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ALTERNATE T-38 TRANSPARENCY DEVELOPMENT
Part I, Initial Analysis and Design

Blaine S. West
Kenneth I. Clayton

University of Dayton Research Institute
300 College Park Avenue
Dayton, Ohio 45469

Final Technical Report for Period January 1979 - September 1980

November 1980

Approved for public release; distribution unlimited.

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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Walter W. Saeger Jr.

CAPT WALTER W. SAEGER, JR.
Project Manager
Improved W/S Protection ADPO
Vehicle Equipment Division

Ralph J. Speelman

RALPH J. SPEELMAN
Program Manager
Improved W/S Protection ADPO
Vehicle Equipment Division

FOR THE COMMANDER:

Ambrose B. Nutt

AMBROSE B. NUTT
Director
Vehicle Equipment Division

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T-38 missions at speeds above the existing crew enclosure damage threshold will result in flight safety risk to aircraft and crew. This report documents the design development of alternate T-38 transparencies having the capability of defeating the impact of a four pound bird at aircraft speeds up to 400 knots. To accomplish the desired windshield/canopy redesign, a feasibility study was conducted, damage probability was determined, the

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birdstrike capability of existing transparencies was experimentally evaluated, edge attachment screening specimens were laboratory tested, and finite element analyses were made. Major findings from each task have been integrated into the detail design of a birdstrike resistant forward windshield panel, recommended for full-scale hardware fabrication, testing, and evaluation. Forward canopy and instructor windshield concepts are also discussed.

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FOREWORD

The effort documented in this report was performed by the Aerospace Mechanics Division of the University of Dayton Research Institute, Dayton, Ohio, under Contract F33615-76-C-3103, Project 2202, "Birdstrike Windshield Technology Program," and Contract F33615-80-C-3401, Project 1926, "Birdstrike Resistant Crew Enclosure Program," for the Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Air Force administrative direction and technical support was provided by Capt. Walter W. Saeger, Jr., AFWAL/FIEA, the Program Manager. The experimental portion of the work was conducted at the Structural Test Laboratory, Experimental and Applied Mechanics Division of the University of Dayton Research Institute. Birdstrike testing was performed at Arnold Engineering Development Center, Arnold Air Force Station, Tennessee.

The work described herein was conducted during the period from January 1979 to September 1980. Project supervision and technical assistance was provided through the Aerospace Mechanics Division of the University of Dayton Research Institute with Mr. Dale H. Whitford, Supervisor and Blaine S. West, Head, Applied Mechanics Group and Project Engineer. The principal investigators were Blaine S. West and Kenneth I. Clayton.

The active support of Capt. Walter W. Saeger, Jr., AFWAL/FIEA, on this project is gratefully acknowledged for his comments, insights, and technical direction. In addition, the authors wish to acknowledge the significant contributions of Mr. Ralph C. Shelton, Subcontract Program Manager at Swedlow, Inc., and to express appreciation to the Arnold Engineering Development Center test personnel for their cooperation and assistance to successfully complete the required work.

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INTRODUCTION

1.1 BACKGROUND

Studies of the hazards presented by bird impact on transparencies date back to the early 1940's. Since that time, the potential damage resulting from bird/aircraft collisions has greatly increased. This is principally the result of increased aircraft speeds that result in both increased energy densities and impulsive forces during the impact process. The problem has been further aggravated by the introduction of low altitude, high speed mission profiles. These flight profiles place the aircraft in areas of high bird density at speeds approaching or exceeding the speed of sound. Birdstrikes under these conditions increase the probability of serious aircraft damage which may result in an aborted mission or loss of aircraft.

The Air Force recognizes the importance of protecting its pilots and at the same time reducing the cost of lost and damaged aircraft. It has been found, from past incidents and impact tests, that the engines and transparent enclosures are the most vulnerable portions of an airplane.

Severe damage and loss of life has, unfortunately, not been an uncommon experience since the 1960's. Two commercial accidents in the early 1960's resulted in the combined loss of 79 lives. Since 1966, the U. S. Air Force has lost more than 10 aircraft worth in excess of $61 million due to bird impacts on transparent enclosures. These include the loss of a T-37B with one fatality, three T-38's with two fatalities, (plus one NASA T-38 lost in 1964 and pilot killed) two F-100's with one fatality, and six F-111's with, fortunately no fatalities. In addition to the $61 million loss in aircraft, and the incalculable loss due to fatalities, an estimated $20 million has been spent in repair costs during the period 1966

through 1972. Further, the role of bird impacts in aircraft losses in South-East Asia is not fully known.

Numerous efforts have been undertaken to make U. S. Air Force aircraft windshield systems more resistant to bird impacts. One example of this is the F-111 Birdstrike Resistant Transparency (BIRT) Development Program initiated by the Flight Dynamics Laboratory in 1972. This program, a number of intermediate programs, and ultimately the F-111 Alternate Design Bird Resistant Transparency (ADBIRT) Program resulted in a dramatic improvement in the birdstrike resistance of the F-111 crew module. The capability, at the most critical location, was increased from 136 knots to 490 knots for the impact of a four-pound bird. This represents an increase in the critical kinetic energy associated with the bird impact event by a factor of 13.

Recently, a number of advanced development programs have been and are being conducted to further examine windshield materials and avoidance concepts. It became apparent from these studies and the F-111 development program that the technological base developed during the 1940's, 1950's and 1960's for bird resistance design is not adequate. Recently the Flight Dynamics Laboratory has funded birdstrike windshield technology programs to develop the technology and methodology to design and analyze aircraft transparencies and support systems exhibiting good structural integrity. The Air Force has made a commitment to develop, demonstrate and apply the technologies required for the design and verification of birdstrike resistant transparent crew enclosures. Specific alternative T-38 transparencies program background is outlined in Figure 1.

1.2 PROGRAM OBJECTIVE

The objective of the program is to apply advances in birdstrike technology to the development and demonstration of

1970

- INCREASED WINDSHIELD THICKNESS FROM 0.28" TO 0.60"
- CANCELLED DEVELOPMENT OF THICKER FORWARD CANOPY

1974

- ATC DRAFTED 300 KT ROC FOR CANOPY

1975

- ROC CANCELLED 30 JAN 75
- CLASS 4A CANOPY SAFETY MOD SUBMITTED 5 MAR
- CANCELLED 2 JUL FOR COSTS & OPERATIONAL COMPLAINTS

1978

- AFFDL/FEW BRIEFED HQ-ATC & SA-ALC/MMSR (7 MAR)
- SA-ALC/MMS REQUESTED FEASIBILITY STUDY (9 MAR)
- FEASIBILITY STUDY INITIATED 15 SEP
  - UNIVERSITY OF DAYTON RESEARCH INSTITUTE (UDRI)
  - SWEDLOW INC.,

1979

- USAF PMD R-P5006(3)

Figure 1. T-38 Windshield/Canopy Program Background.

an improved cost-effective T-38 crew enclosure (reference Figure 2) having the capability of defeating the impact of a four-pound bird at aircraft speeds up to 400 knots.

1.3 DESIGN APPROACH

The successful design/analysis of bird resistant crew enclosure structures is a complex problem, characterized by geometric and material nonlinearities and by coupling of the bird induced load with the structural response. Therefore, the structural design/analysis approach for bird impact should be a systems analysis approach similar to that commonly applied to a primary structural system. Low priority or secondary considerations for transparency design apparently evolved when aerodynamic considerations overcame structural requirements. The development history of a bird impact resistant crew enclosure for the F-111 aircraft illustrates the shortcomings of pursuing the design of each component in the system independently. In contrast, significant performance gains were achieved through a systems design approach accompanied by savings in weight and cost. Increased capability, from an estimated 136 knots to greater than 491 knots, represents an increase in kinetic energy of the bird by a factor of 13. The successful execution of the alternate T-38 transparency redesign effort is being accomplished by melding the supporting parameters into the development cycle presented in Figure 3.

1.4 SCOPE

In order to successfully accomplish a windshield/canopy transparency redesign which provides the desired improvement in birdstrike capability, specific tasks were identified as follows:

(a) Preliminary design and evaluation (Feasibility Study),

(b) birdstrike risk assessment,

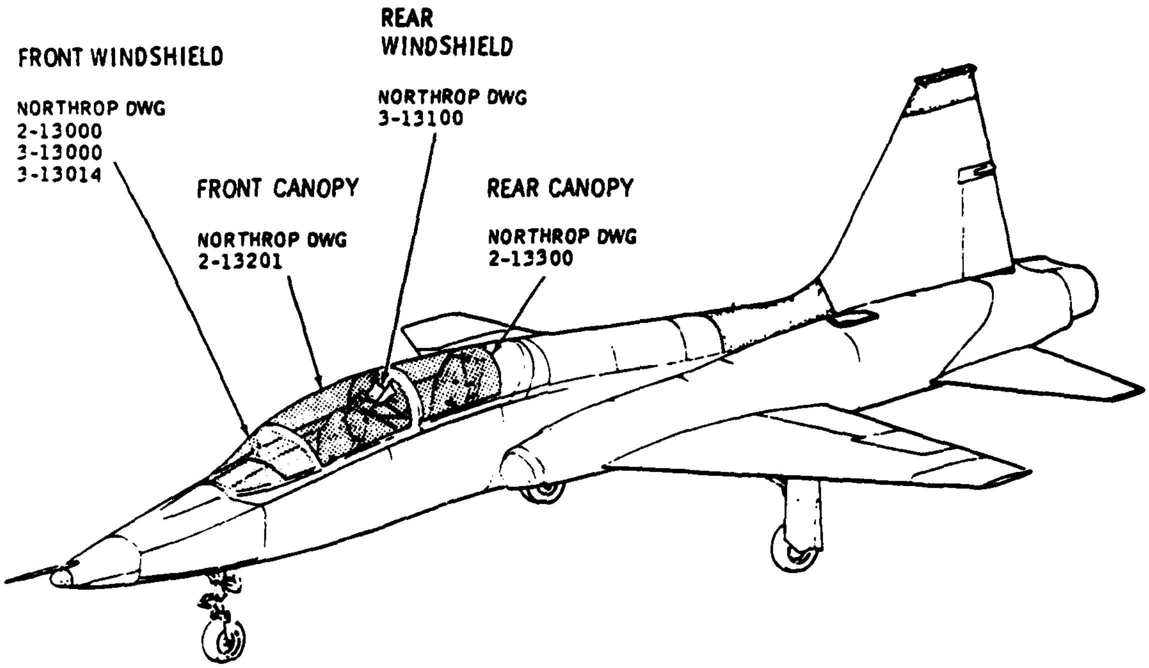

Figure 2. T-38 Crew Enclosure.

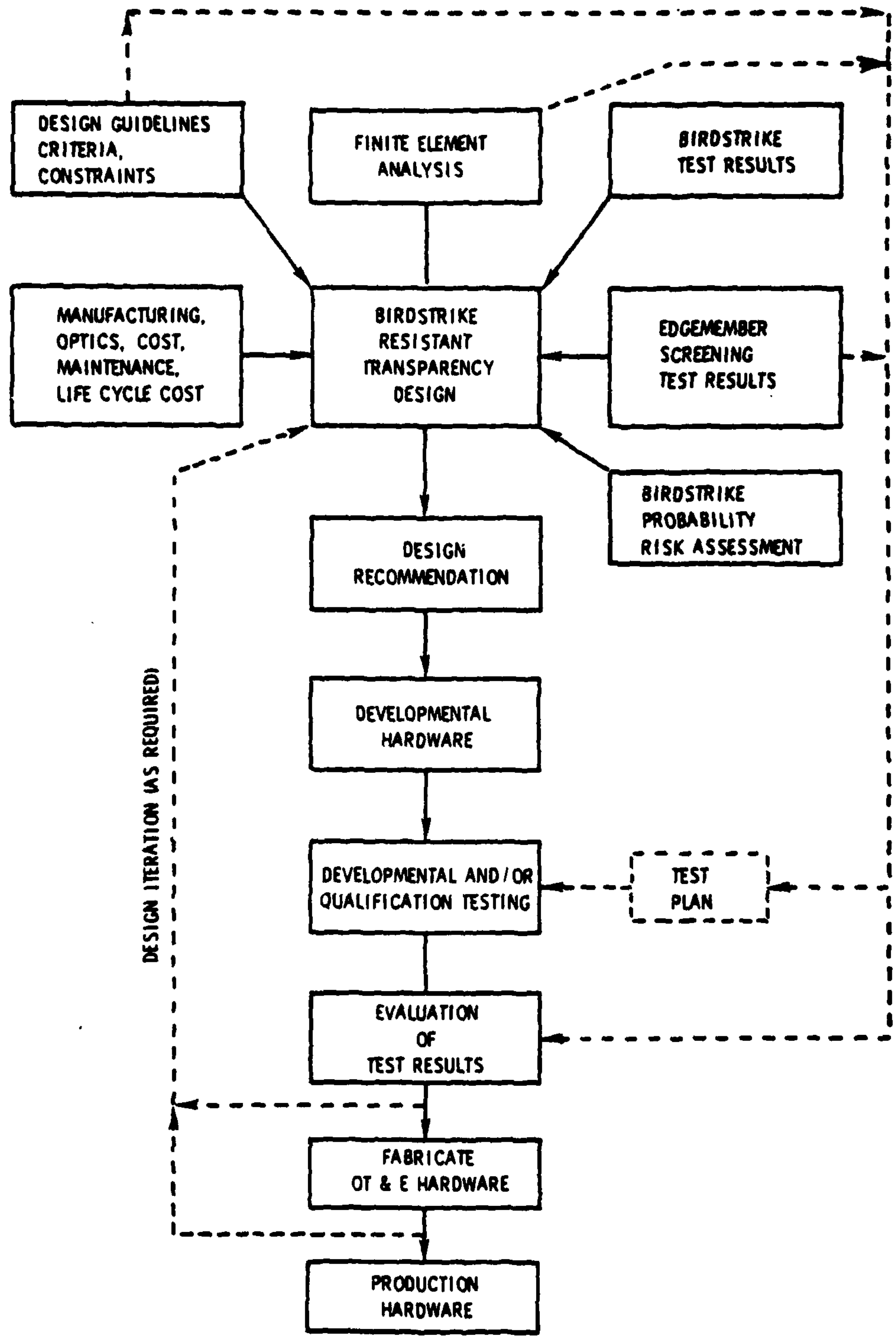

Figure 3. Proposed Alternate T-38 Transparency Development Cycle.

(c) experimental evaluation of birdstrike capability of existing transparencies,

(d) edge attachment screening,

(e) finite-element analysis, and

(f) bird resistant detail design.

The report briefly summarizes the major findings of each task and integrates the findings into design recommendations.

SECTION 2

PRELIMINARY DESIGN AND EVALUATION (FEASIBILITY STUDY)

The first step to determine the feasibility of upgrading the T-38 aircraft crew enclosure forward transparencies (student windshield and student canopy) to be compatible with current and expected usage, is to evaluate preliminary and potential designs. The University of Dayton Research Institute (UDRI), coupled with technical service support from Swedlow, Inc., has accomplished this requirement. The experience of Swedlow, Inc., with monolithic and laminated polycarbonate and acrylic parts, transparency edge design, and knowledge gained through the production of T-38 transparencies provided expertise to make critical decisions relating to optics, fabrication, maintainability, tooling, and life cycle costing. As part of this effort, the UDRI/Swedlow team, in conjunction with the AFFDL Project Engineer, defined the guidelines and constraints that will govern the modifications, defined candidate transparency cross-sections, assessed the cost and optics performance of each candidate design concept, assessed the maintainability requirements and limitations imposed by each configuration, and conducted birdstrike probability studies to evaluate the cost effectiveness of a retrofit program.

The preliminary design guidelines used to conduct the feasibility study are enumerated below.

(a) The student (forward) windshield and student (forward) canopy will be considered for redesign;*

(b) present study canopy life is 4,000-5,000 hours (8-10 years);

(c) present student windshield life is 4,000-5,000 hours (8-10 years);

(d) through the canopy ejection capability will not be mandatory for student canopy;*

---

*HQ-ATC later determined that it was necessary to retain through the canopy (TTC) ejection capability for the student canopy, at which time the aft windshield was included for study to provide interim birdstrike protection for the instructor pilot.

(e) present T-38 fleet size is 1,000 aircraft,

(f) all feasibility studies will be based on remaining fleet life of 10 and 20 years;

(g) T-38 fleet size is assumed to remain at present level for assumed fleet life spans;

(h) today's value of fully equipped T-38 aircraft is assumed at $1.5 million;

(i) primary fuselage structure will not be affected by the redesign effort; and

(j) basic transparency edge design and attachment will be adequate for upgraded transparencies.

The preliminary design constraints used to conduct the feasibility study are enumerated below.

(a) No decrease in maintainability with respect to existing transparencies;

(b) optics requirements to meet or exceed current Northrop Process Specifications IT-51 and IT-33;

(c) minimization of overall weight increase and center of gravity change;

(d) no redesign of primary structure;

(e) no major redesign of canopy operating mechanism or crew equipment;

(f) minimization of changes to exterior moldline, fairings, and associated hardware;

(g) minimize transparency outer ply spall during bird impact event;

(h) maintain interchangeability with existing transparencies if possible;

(i) simplification of fleet retrofit, preferably at field level but with no more than depot level facilities required; and

(j) capability to withstand hot powder from aircraft cannon to be equivalent to existing transparencies.

The governing guidelines and constraints were subdivided into "must" requirements and "want" requirements. The "must" requirements are those which must be totally satisfied, and included:

- four pound-400 knots birdstrike capability,
- producibility, and
- interchangeability.

The selected design is to satisfy the "must" requirements and will consist of a compromise among and an optimization of remaining requirements according to their relative importance. These other desired requirements are "want" requirements and are in the form of performance in certain key properties, namely:

- optics,
- cost,
- edge attachment configuration, and
- weight.

In general, available test data indicates that laminated polycarbonate panels separated by low modulus ductile interlayers offer high strength/weight performance for center panel bird impact. The opportunities to vary stiffness and strength and thus performance are almost limitless. One may depart from balanced laminates and vary the thickness of the structural plies and the thickness and material properties of the interlayers. However, there are many considerations to panel design other than center panel impact, and these may well dictate the choice of a monolithic polycarbonate panel. Some of these other considerations are discussed briefly in the following paragraphs.

Structurally, edge design is very important and may prove to be critical for birdstrikes near the panel edge. The importance of considering total system response, edge member

cross-section, and the details of edge member attachment are clearly demonstrated in References 1 through 6.

Optics are critical, and especially when based on viewing the T-38 student's windshield (forward) and student's canopy (forward) from the instructor's position (aft) as defined in Northrop Specification IT-33, Revision E. The optics requirement is thus an important factor which affects the choice of monolithic or laminated panels and the composition of the laminated panels. As with any flightworthy components, the weight of the transparency assemblies is of concern and should be held to a minimum.

Serviceability and life of candidate windshield/canopy transparencies are also key factors in selecting a design. The present monolithic stretched acrylic transparencies offer good serviceability and life excepting the birdstrike requirement.

---

[1] F. L. Pretzer, R. L. Peterson, and B. S. West, Design for Bird Impact: A Structural Systems Problem. (Paper presented at the Conference on Aerospace Transparent Materials and Enclosures, Long Beach, California, 24-28 April 1978; published as AFFDL-TR-78-168, December 1978.)

[2] B. S. West, and P. E. Johnson, Laboratory Screening Tests: A Cost Effective Approach to Aircraft Transparency Design. (Paper presented at the Conference on Aerospace Transparent Materials and Enclosures, Long Beach, California, 24-28 April 1978; published as AFFDL-78-168, December 1978.)

[3] B. S. West, Design and Testing of F-111 Bird Resistant Windshield/Support Structure, Volume I - Design and Verification Testing. (AFFDL-TR-76-101, Volume I, December 1976.)

[4] Paul E. Johnson, Design and Testing of F-111 Bird Resistant Windshield/Support Structure, Volume II - Mechanical Properties Evaluation. (AFFDL-TR-76-101, Volume II, December 1976.)

[5] Analysis of Shock-Absorbing Concepts for Bird-Proof Windshields of Advanced Air Force Vehicles. (AFFDL-TR-74-155, February 1976.)

[6] Bird Strike Capabilities of Transparent Aircraft Windshield Materials. (AFML-TR-74-234, December, 1974.)

The use of polycarbonate will increase the birdstrike capability for a given thickness. In order to protect the surfaces of monolithic polycarbonate transparencies, protective coatings must be applied. Historically, these treatments are not as durable as stretched acrylic. With laminated polycarbonate assemblies, the outer plies can be thin stretched or as-cast acrylic layers to provide the serviceability and surface resistance equivalent to those of the present panels.

It is obvious that the best possible transparency is not desirable if it cannot be produced, or produced within the required tolerances. Hence the manufacturing trade-off becomes a key variable to be considered early in the choice of candidate design configurations. Another significant factor, or variable, which has been considered in the optimization of the design configuration is life-cycle cost of the transparency assemblies.

Specific polycarbonate and stretched acrylic thickness versus penetration velocity (for four-pound bird center impact) curves were generated and are presented as Figures 4 and 5 for the T-38 windshield and canopy configurations respectively. Each curve, in the range of interest, considers 45° flat panel data generated by Goodyear Aerospace Corporation and the National Research Council of Canada, adjusted to 27½° (windshield) and 20½° (canopy) by the ratio of sines, and translated to coincide with full scale data generated by T-38, F-15, and F-16 bird impact tests. Also taken into consideration was data generated by Hawker Siddeley Aviation Ltd., for Concorde application. Portions of the curves are projected estimates of material behavior. Any reduction due to edge impact is dependent on the adequacy of the edge attachment design.

Baseline cross-sections of the existing T-38 student windshield and student canopy are:

(a) Windshield: 0.600 in. stretched acrylic at a nominal weight of 34 pounds;

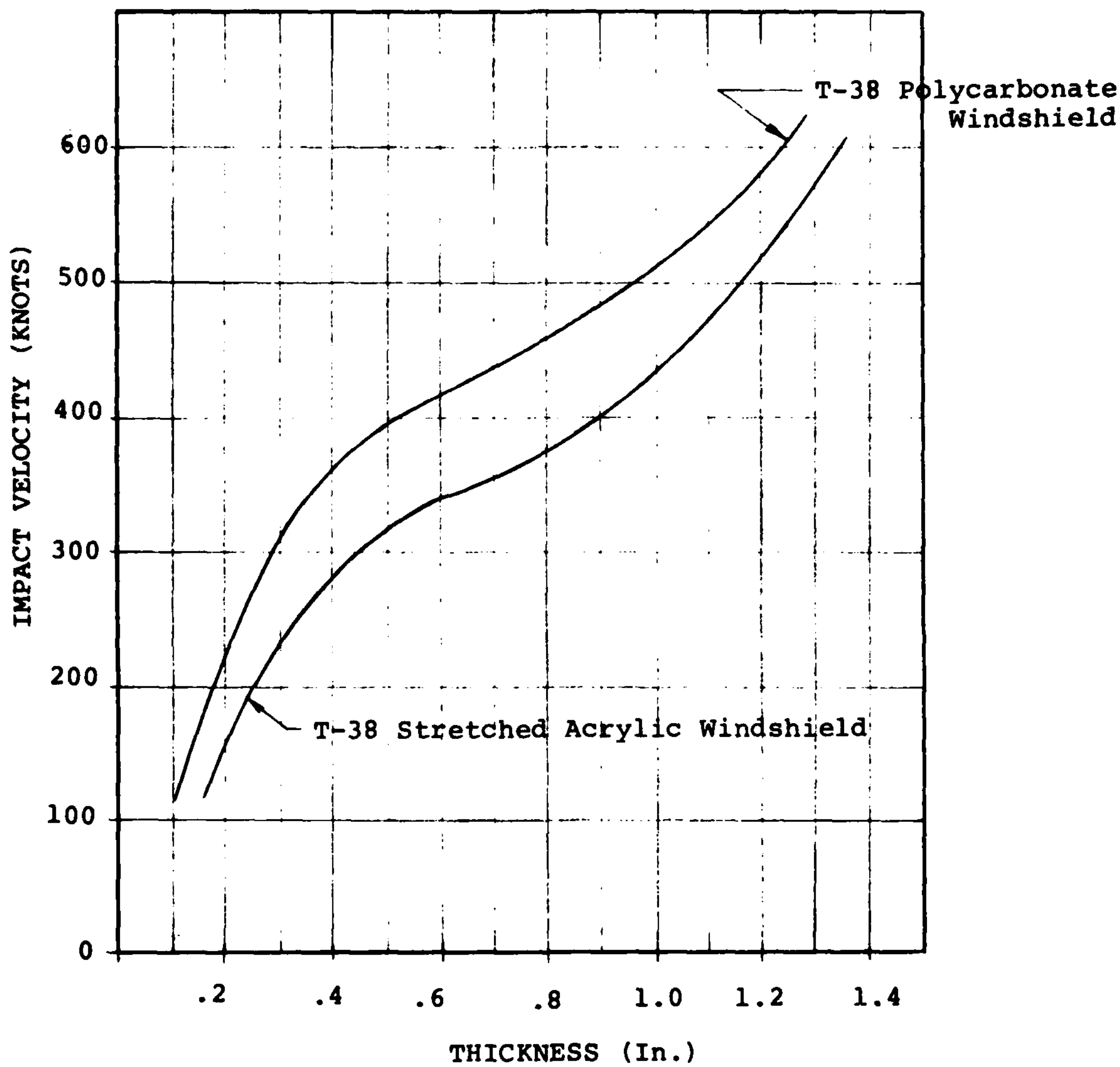

Figure 4. Polycarbonate and Stretched Acrylic Thickness Versus Penetration Velocity of Four-Pound Bird Center Impact for T-38 Windshield Configuration.

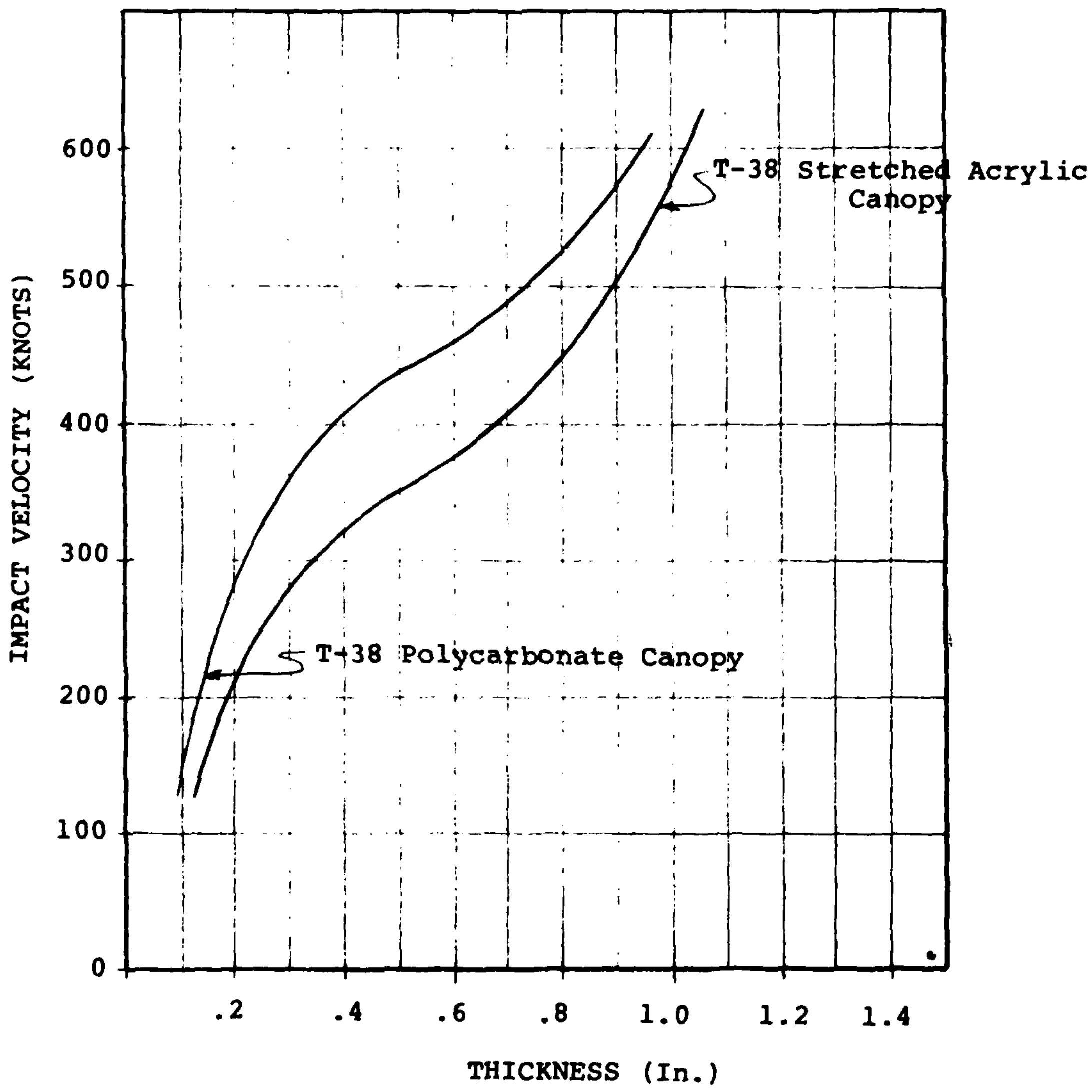

Figure 5. Polycarbonate and Stretched Acrylic Thickness Versus Penetration Velocity of Four-Pound Bird Center Impact for T-38 Canopy Configuration.

(b) Canopy: 0.230 in. stretched acrylic at a nominal weight of 32 pounds.

Twelve preliminary candidate windshield transparency cross-sections and 11 preliminary candidate canopy transparency cross-sections were defined to satisfy the four-pound 400 knot birdstrike requirement. These minimum thickness cross-sections, considering various combinations of monolithic and laminated acrylic and/or polycarbonate as shown in Figures 6 and 7, were identified and configured based on the experience of UDRI, Swedlow, Inc., and the Air Force and were assessed in each of the key requirement areas.

At the conclusion of the preliminary design and evaluation study, the UDRI, in concurrence with the AFWAL/FIEA Project Engineer, selected five windshield- (Figure 8) and three canopy- (Figure 9) transparency configurations which best satisfied the evaluation criteria. The selected configurations were presented as candidates for further evaluation at an Air Force T-38 Forward Transparencies Program Review which was conducted by AFWAL/FIEA on 12 June 1979 at Randolph Air Force Base for HQ-ATC and SA-ALC personnel.

It was noted that one of the preliminary design guidelines established that through the canopy ejection capability will not be mandatory. During discussions following the program review, HQ-ATC commented that they would determine if such a requirement is necessary and inform AFWAL/FIEA of their decision for incorporation into the transparency redesign. Subsequently, HQ-ATC did determine and inform AFWAL/FIEA that it is necessary to maintain through-the-canopy ejection capability. Therefore, further design development efforts on the forward (students) canopy is being redirected to define a viable approach to incorporate through-the-canopy ejection capability with the requirement for defeating the impact of a four-pound birdstrike at 400 knots.

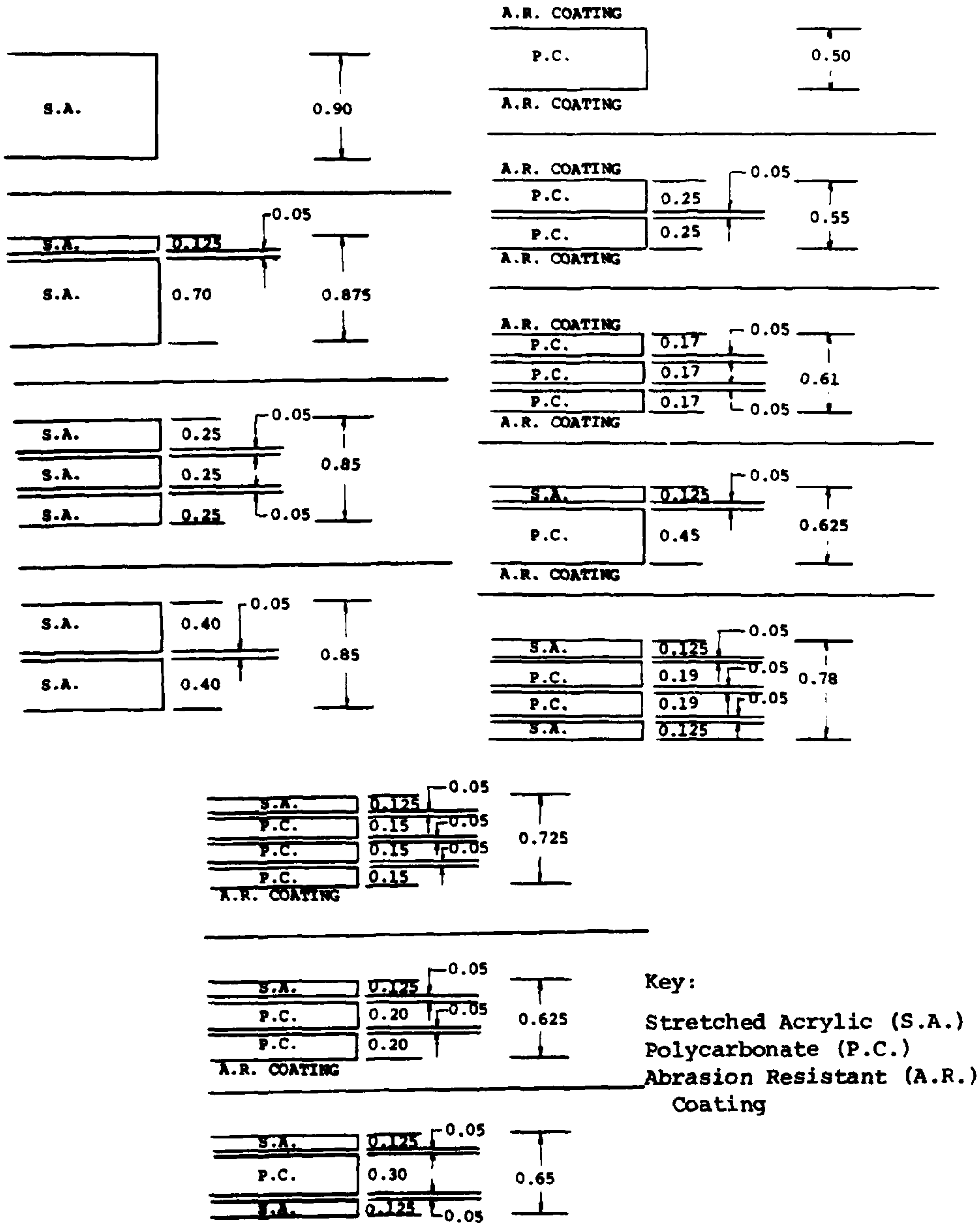

Figure 6. Candidate Windshield Transparency Cross-Sections.

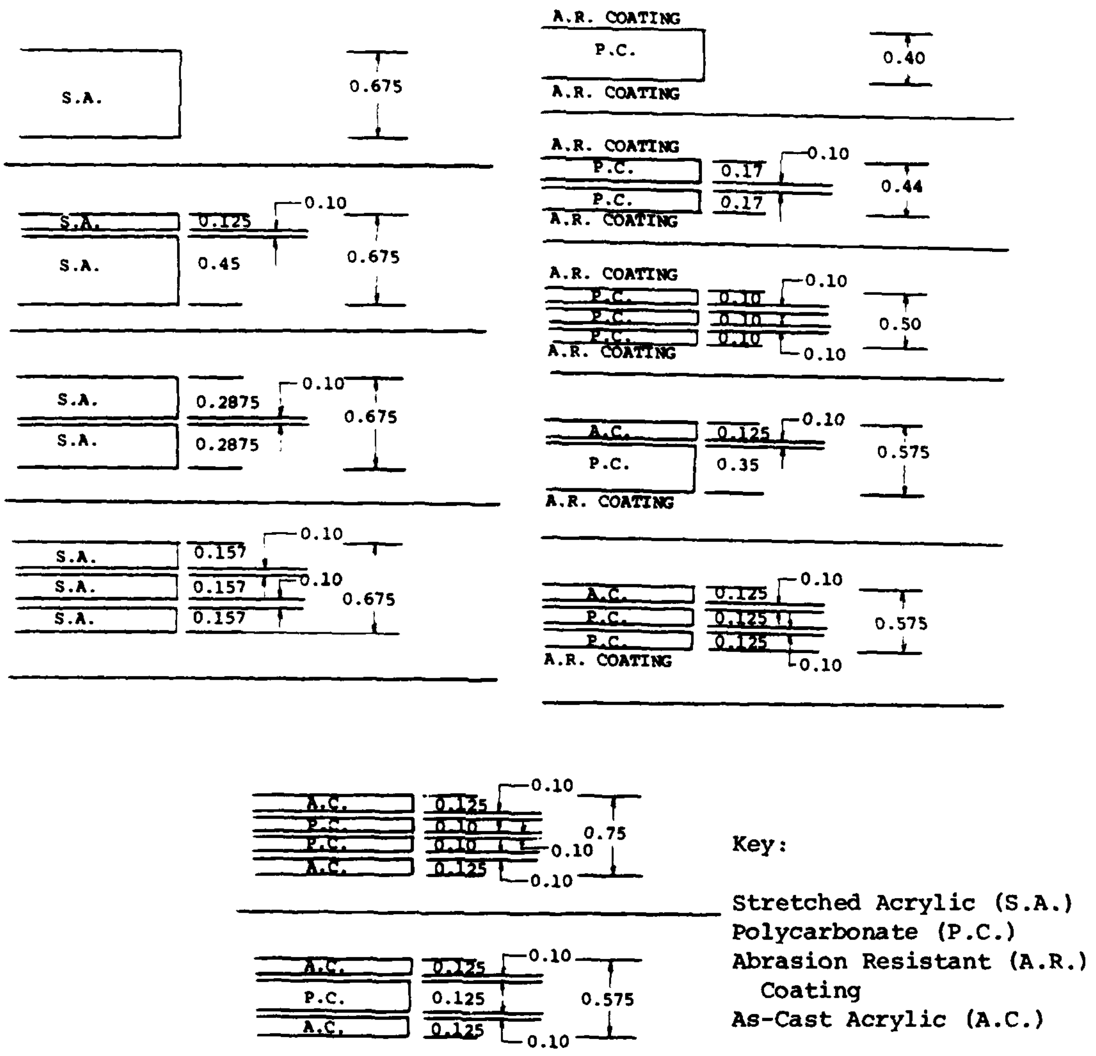

Figure 7. Candidate Canopy Transparency Cross-Sections.

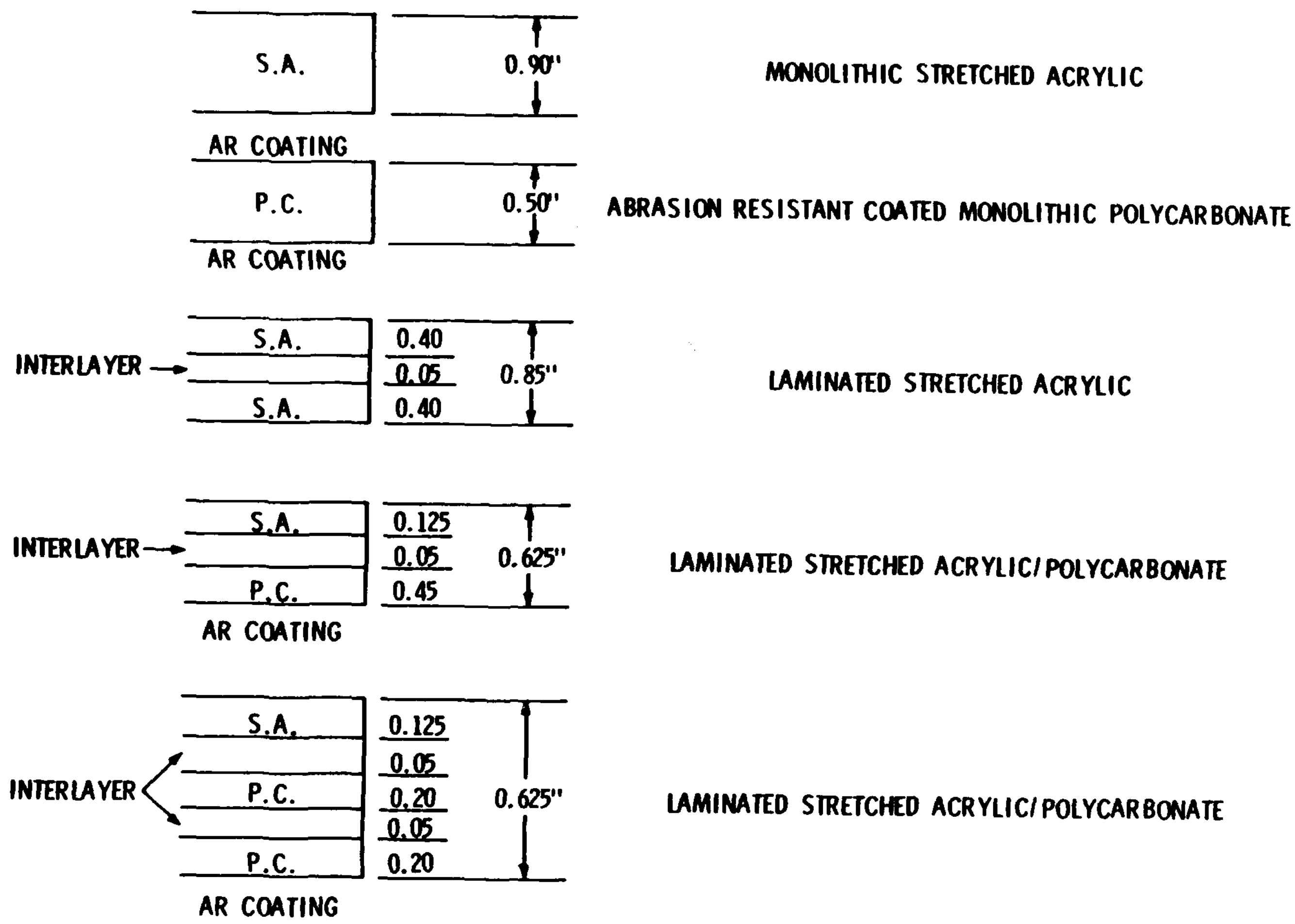

Figure 8. Selected Windshield Candidate Configurations.

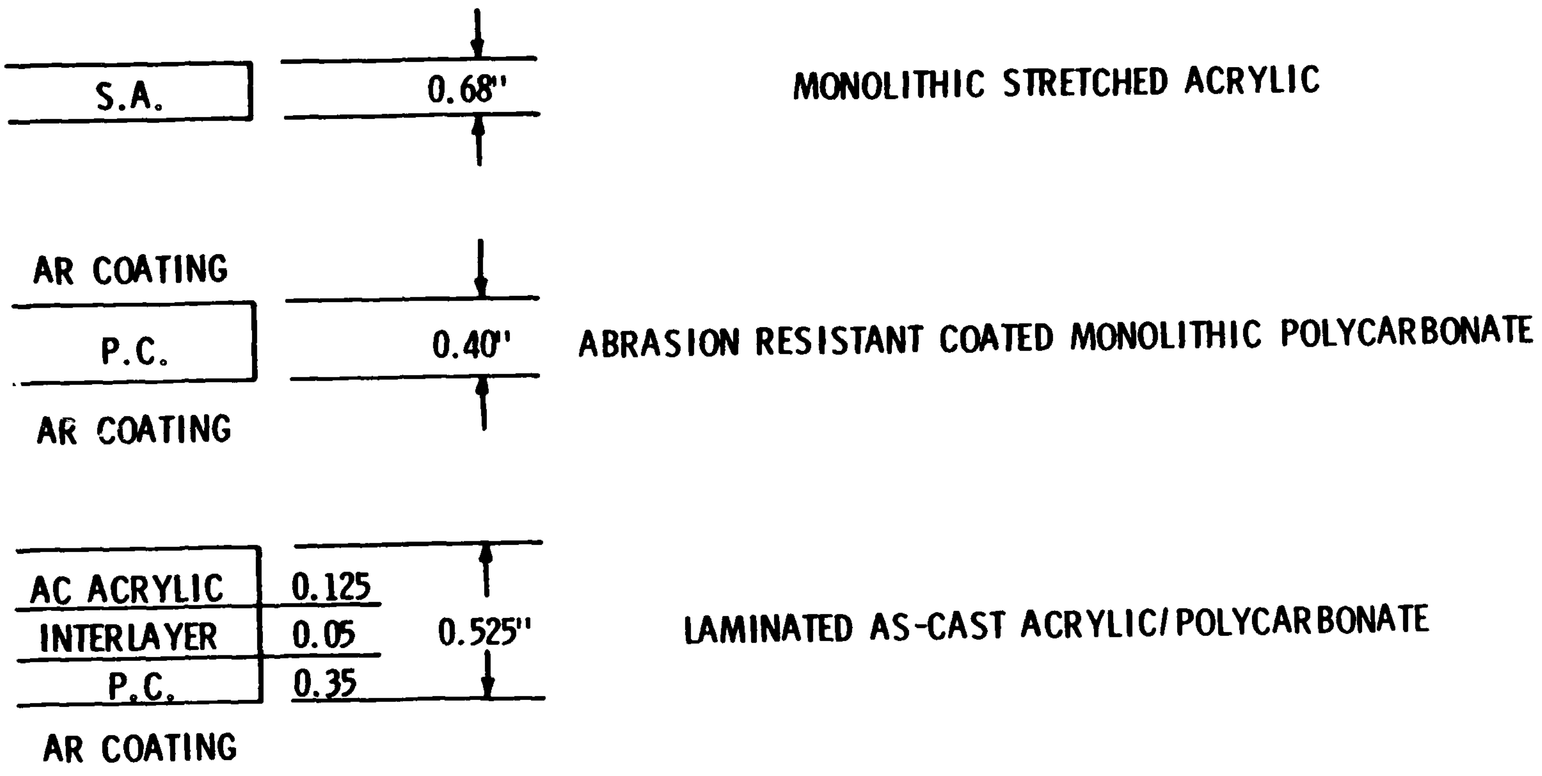

Figure 9. Selected Canopy Candidate Configurations.

As a result of the decision, the scope of the original effort described in Paragraph 1.4 was expanded to experimentally investigate the feasibility of upgrading the T-38 instructor's windshield to provide birdstrike protection for the instructor pilot as an interim measure until a student canopy with upgraded birdstrike protection and TTC ejection capability becomes available. This effort is described in Paragraph 4.2.

SECTION 3
BIRDSTRIKE RISK ASSESSMENT

Currently, the T-38 student windshield consists of nominal 0.60-inch thick stretched acrylic and the student canopy consists of nominal 0.23-inch thick stretched acrylic. Figure 10 presents estimated strength distributions, which were generated internally by UDRI, for the existing windshield and canopy. The Reference 7 report utilizes a statistical model to predict the number of damaging birdstrikes to the existing T-38 windshield and canopy during the next ten years for each of four velocity distributions. Rationale used in modeling these components were dependent on the operational density and weight distribution of birds in the aircraft environment, the forward projected area of the hardware, the aircraft velocity distribution in the bird environment, and the total time spent in the bird environment. Total flight time was obtained from the data files on birdstrikes maintained at Norton Air Force Base; a T-38 cockpit birdstrike history being presented in Table 1. Table 2 presents the predicted T-38 transparency penetrations for the 10-year period.

During the period August 6-29, 1979, fifteen full-scale bird impact shots were made at AEDC to experimentally establish T-38 forward transparencies capability as described in Section IV. Subsequently, strength distributions for the forward transparencies were revised in accordance with Figure 11 and input to the probability model to iterate the number of damaging strikes. Resultant data are shown in Table 3 with previous results based on the estimated capability of Figure 10 shown in parenthesis where changes occur.

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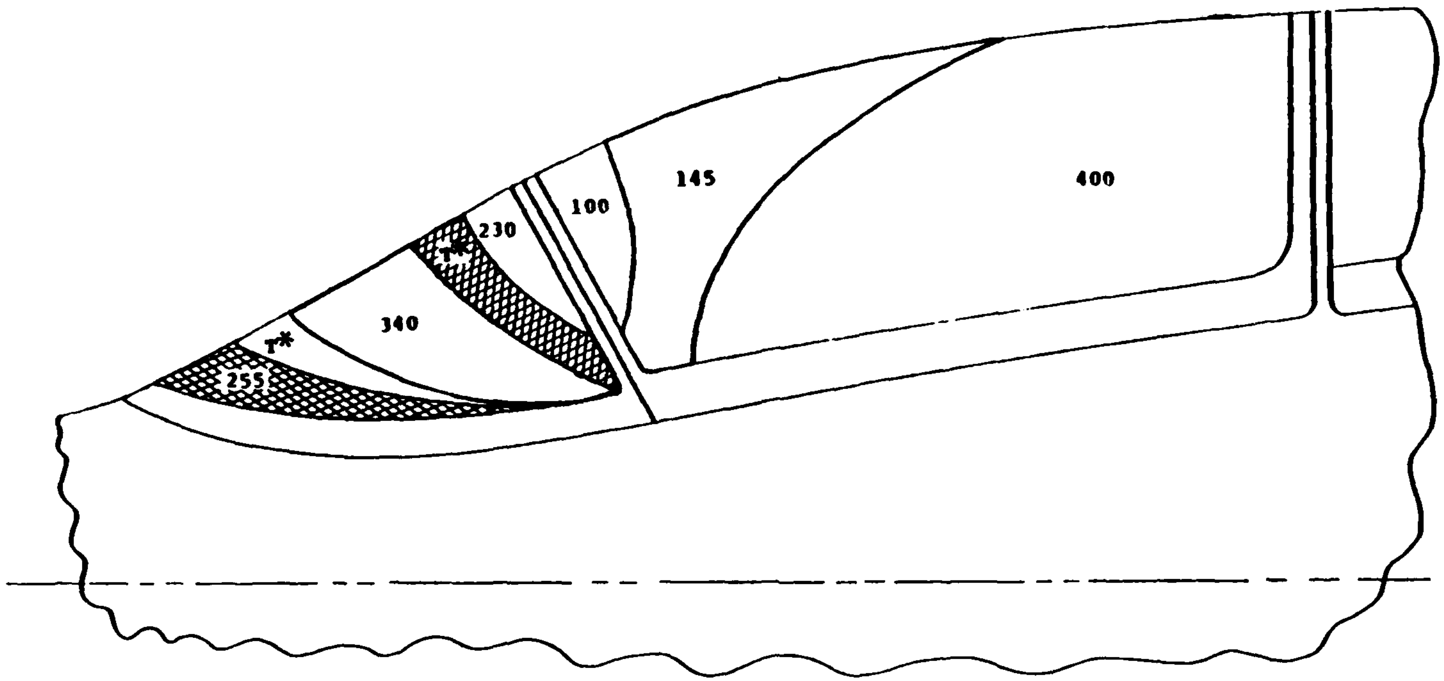
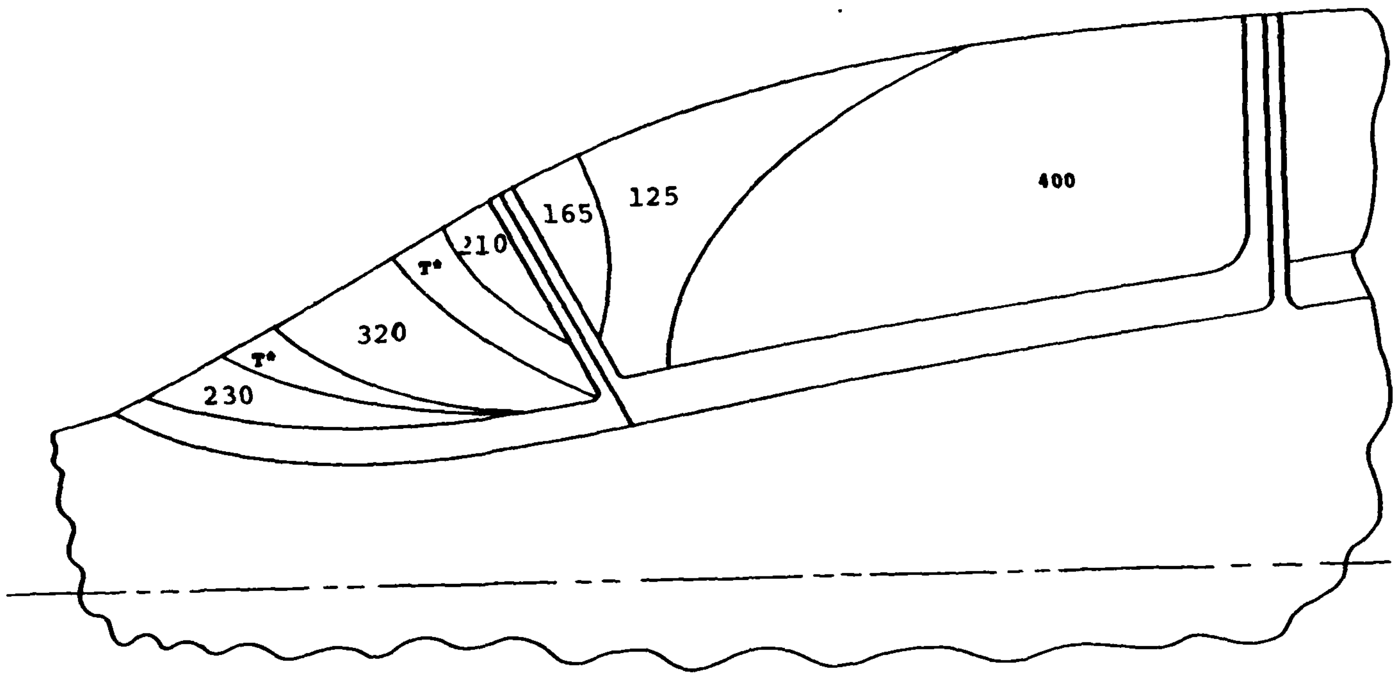
[7] A. P. Berens, Evaluation of the Birdstrike Threat to T-38 Transparencies. (UDRI-TM-79-12, University of Dayton Research Institute, Dayton, Ohio, July 1979.)



*TRANSITION ZONE

IMPACT VELOCITY IN KNOTS

Figure 10. Estimated T-38 Existing Transparency Capability.



* Transition Zone
Impact Velocity in Knots

Figure 11. Existing Transparency Capability.

TABLE 1

T-38 COCKPIT BIRDSTRIKE HISTORY

	WINDSHIELD REPORTED/DAMAGING	FWD CANOPY REPORTED/DAMAGING	TOTAL REPORTED/DAMAGING	COMMENTS
1964	*/1	*/1	*/2	NASA T-38 LOST, PILOT KILLED EJECTED BELOW MIN.
1965	*/3	*/0	*/3	
1966	*/0	*/0	*/0	NO REPORT AVAILABLE
1967	*/1	*/2	*/3	T-38 DESTROYED, 1 PILOT KILLED
1968	0/0	2/0	2/0	
1969	5/0	3/0	8/0	
1970	4/1	1/0	5/1	T-38 DESTROYED, ENG. FODed BY SPALL
1971**	49/1	16/3	65/4	PILOT INJURED BY FRAGMENTS
1972	4/1	3/3	7/4	IP EJECTED, SP LANDED ACFT
1973	3/3	1/0	4/3	
1974	3/1	2/2	5/3	T-38 DESTROYED, 2 ENGS. FODed BY CANOPY SPALL IP KILLED - LATE EJECTION
1975	1/0	1/1	2/1	
1976	0/0	1/0	1/0	
1977	1/0	0/0	1/0	
1978	4/2	1/1	5/3	18" HOLE IN CANOPY, NO REPORTED INJURIES

* DATA REPORTED FOR 1964-67 WAS ONLY FOR MAJOR INCIDENTS AND AS TOTAL STRIKES FOR TRAINER A/C AS A GROUP.

** IN 1971, ALL BIRDSTRIKES WERE REPORTED REGARDLESS OF SEVERITY.

TABLE 2

T-38 BIRDSTRIKE PROBABILITY STUDY

VELOCITY DISTRIBUTION	BASELINE*	PREDICTED TRANSPARENCY PENETRATIONS FOR A 10 YEAR PERIOD		
		BASELINE + 3 LOW LEVEL MISSIONS/STUDENT	BASELINE + 6 LOW LEVEL MISSIONS/STUDENT	BASELINE + 9 LOW LEVEL MISSIONS/STUDENT
WINDSHIELD				
EXISTING CAPABILITY	1.6	2.0	2.5	3.2
NOMINAL 400 KT CAPABILITY	0.3	0.5	0.7	1.0
CANOPY				
EXISTING CAPABILITY	5.5	6.3	7.1	8.1
NOMINAL 300 KT CAPABILITY	0.6	0.8	1.0	1.3
NOMINAL 350 KT CAPABILITY	0.3	0.4	0.5	0.7
NOMINAL 400 KT CAPABILITY	0.1	0.2	0.3	0.4

*BASELINE FOR MODEL USES FLIGHT VELOCITY PROFILE ACTUALLY RECORDED IN 1967-72.

TABLE 3

PROBABILITY OF A BIRDSTRIKE PENETRATING
T-38 EXISTING TRANSPARENCY

Velocity Distribution	Windshield	Canopy
Observed	0.0628 (0.0470)	0.2577 (0.310)
Obs. Mod 1	0.0721 (0.0555)	0.2728 (0.325)
Obs. Mod 2	0.0791 (0.0619)	0.2833 (0.335)
Obs. Mod 3	0.0901 (0.0722)	0.2984 (0.350)

	Expected Strikes During Next 10 Years		Expected Bird Penetrations of Existing T-38 Enclosures During Next 10 Years	
Velocity Distribution	Windshield	Canopy	Windshield	Canopy
Observed	33.4	17.9	2.1 (1.6)	4.6 (5.5)
Obs. Mod 1	36.6	19.4	2.6 (2.0)	5.3 (6.3)
Obs. Mod 2	40.2	21.3	3.2 (2.5)	6.0 (7.1)
Obs. Mod 3	43.7	23.1	3.9 (3.2)	6.9 (8.1)

SECTION 4
BASELINE CAPABILITY

4.1 FORWARD (STUDENT) WINDSHIELD/CANOPY

From 28 March 1968 to 28 May 1968, Northrop personnel conducted T-38 bird impact resistivity tests as documented in Northrop Report NOR-68-121 and by high-speed photography. All test articles were installed on a T-38 forward fuselage. Except for two off-center (15° yaw) shots, all shots were aimed at the vertical/horizontal centerline of the windshield panels and parallel to the airplane centerline. Monolithic and laminated stretched acrylic windshields and a monolithic stretched acrylic canopy resisted failure as a result of four-pound bird impact as follows:

Transparency Panel Thickness	Panel Type	Bird Impact Velocity (knots)
.28	Monolithic	Failed
.42	Laminated	177
.60	Monolithic	319
.60	Laminated	290
.80	Monolithic	373
.91	Laminated	395
.40	Monolithic (Canopy)	173

A series of full-scale bird impact tests on current T-38 flight hardware was conducted at Arnold Engineering and Development Center (AEDC), Arnold Air Force Station, Tennessee, during the period 6 August 1979 to 22 August 1979. The UDRI supported the AFWAL/FIEA in establishing shot locations, shot velocities, test instrumentation, and on-site monitoring of these tests. Details of this testing are documented in the Reference 8 Report.

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[8] B. S. West, Alternative T-38 Transparencies, Baseline Birdstrike Testing. AFWAL-TR-80-3132, Part II, November 1980.

In summary, the tests provided data to:

(a) establish existing edge capabilities for both the student windshield and canopy,

(b) refine input into the birdstrike probability studies,

(c) verify capability of support structure, and

(d) support bird resistant crew enclosure redesign.

Based on the full-scale T-38 birdstrike test data, the current student windshield has a nominal center impact capability of 320 knots which is reduced to approximately 210 knots along the aft edge and 230 knots along the forward edge; the current student canopy provides a nominal protection level of 160 knots along the forward arch, decreasing to a nominal 125 knots at an impact location 14 inches aft of the forward arch (reference Figure 11).

4.2 INSTRUCTOR'S (AFT) WINDSHIELD

During August-September 1980, a series of four-pound bird impact tests on current 0.460 inch thick stretched acrylic T-38 instructor windshields and on 0.500 inch thick uncoated polycarbonate instructor windshields, mounted on flight hardware, were conducted at the UDRI air cannon (Impact Physics) facility. A summary of test results obtained to date is presented in Table 4.

TABLE 4

INSTRUCTOR WINDSHIELD - FOUR POUND BIRDSTRIKE TEST DATA

Shot No.	Velocity	Description
1	174 ft/sec (103 knots)	High center impact location on acrylic. No damage.
2	178 ft/sec (105 knots)	High center impact location on acrylic. No damage.
3	219 ft/sec (130 knots)	High center impact location on acrylic. Failed a tie rod which resulted in subsequent failure of other tie rod and a crack in the frame at the lower windshield mounting location.
4	212 ft/sec (125 knots)	Center shot on acrylic, 30% stronger replacement tie rods, failed acrylic.
5	194 ft/sec (115 knots)	Center shot on polycarbonate. No damage.
6	259 ft/sec (153 knots)	Center shot on polycarbonate. Pulled poly out of frame on sides. Bent lip over on lower frame, cracked sides of frame, sheared bolt on lower support rod.
7	190 ft/sec (112 knots)	Corner shot on polycarbonate. No damage.
8	235 ft/sec (139 knots)	Corner shot on polycarbonate, bent lip back 1/2 inch on lower frame.
9	285 ft/sec (169 knots)	Corner shot on polycarbonate, knocked out windshield, tore out part of the lower frame.

SECTION 5

TRANSPARENCY/SUPPORT STRUCTURE INTERFACE

Structurally, edge attachments are a primary design consideration, especially when impacts are near the edges. The generation of design tradeoff data required to finalize the T-38 alternate transparency cross-section and associated edge design would be prohibitive in terms of dollars, manpower, availability of parts, and calendar time if fully obtained from the testing of full-scale flight hardware. Therefore, UDRI has screened the five windshield and four canopy configurations, shown in the Appendix, in the laboratory. The flexure beam construction simulated the candidate transparency cross-sections described in Section 2 and the canted fuselage station 184.35 shown in Figure 12. Figure 13 presents sketches, identification, and data summary for three-point loaded beams tested with simulated T-38 edge fixity at a displacement rate of 2000 inches per minute using the University's high performance, electrohydraulic closed-loop (MTS) system; the test procedure being similar to that employed in screening F-111 specimens as documented in Reference 4. The test specimens, representative of aircraft baseline and proposed edge constructions, were manufactured in a T-38 production environment by Swedlow, Inc.

Initial tests subjected windshield beams having slotted edge attach holes to center of beam impact (13.50 inch span; 6.75 inch 1/2 span) and canopy beams having clamped edges to center of beam impact. All proposed edge designs exceeded the ultimate load capability of the baseline design. Excessive deflection resulted in edge pullout at the slotted holes, without failure, of the polycarbonate windshield candidate design (Configuration #4). Therefore, additional off-center

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[4] Paul E. Johnson, Design and Testing of F-111 Bird Resistant Windshield/Support Structure, Volume II - Mechanical Properties Evaluation. (AFFDL-TR-76-101, Volume II, December 1976.)

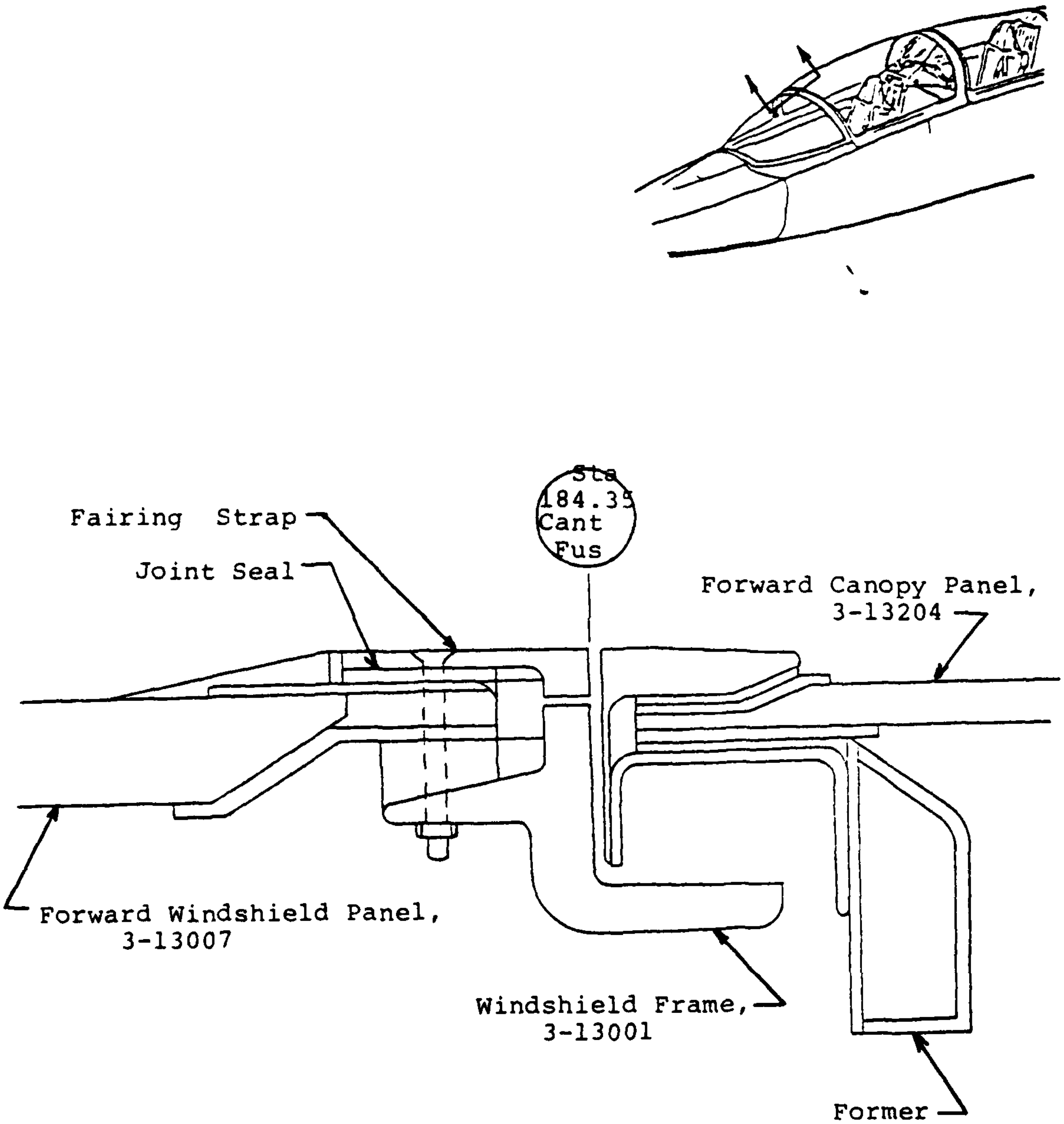
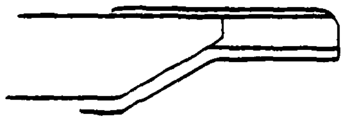


Figure 12. Canted Fuselage Station 184.35 Support Structure.

T-38 FORWARD WINDSHIELD   EDGE ATTACH SCREENING TESTS 3-pt. load, unless noted

Load-displacement measured at 2000 in/min unless noted



P_{ULT} = 825 lbs. @ δ = 0.83"

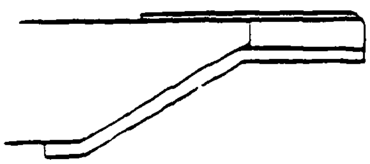
P_{YLD} = 515 lbs. @ δ = 0.28"

Edge failure at butt joint

P_{ULT} = 1000 lbs. @ δ = 0.85"

P_{YLD} = 438 lbs. @ δ = 0.17" (4-pt. load)

Configuration #1, Drawing 79200 - Baseline (.60 acrylic)



P_{ULT} = 1400 lbs. @ δ = 0.55"

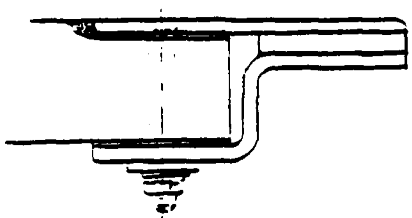
P_{YLD} = 1040 lbs. @ δ = 0.26"

Edge failure at butt joint

P_{ULT} = 1750 lbs. @ δ = 0.50"

P_{YLD} = 1250 lbs. @ δ = 0.25" (4-pt. load)

Configuration #2, Drawing 79201 - 400 Knot (.90 Acrylic Bonded)



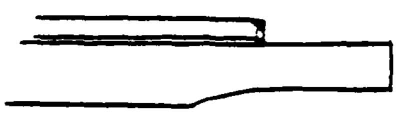
P_{ULT} = 3398 lbs. @ δ = 1.08"

Acrylic failed at point of impact except at 2"/min run = edge attach failure @

P_{ULT} = 3075 lbs., δ = 1.93"

P_{YLD} = 2300 lbs., δ = 0.99"

Configuration #3, Drawing 79208 - 400 Knot (.90 Acrylic Bolted)



P = 1410 lbs. @ δ = 1.94"   6.75" ↓ 6.75" ↑ 1/2 span ↑

No Failure

P = 1950 lbs. @ δ = 1.68"   4.5" ↓ 4.5" ↓ 4.5" ↑ 1/3 span ↑

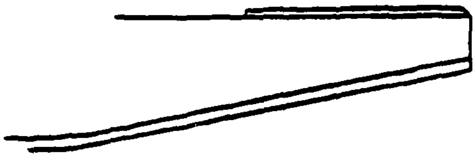
No Failure

P = 2400 lbs. @ δ = 1.30"   3.375" ↓ 6.75" ↓ 3.375" ↑ 1/4 span ↑

No Failure

Configuration #4, Drawing 79210 (Polycarbonate)

Figure 13. Summary of T-38 Laboratory Screening Tests.



P_{ULT} = 2788 lbs. @ δ = 0.98"

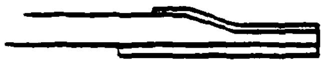
Acrylic failed either at point of Impact (℄ beam) or at thickness transition

Configuration #9, Drawing 79207 - Modified Edge (.90 Acrylic)

T-38 FORWARD CANOPY

EDGE ATTACH SCREENING TESTS

Load vs. displacement measured at 2000 in/min.
3 pt. load



P_{ULT} = 340 lbs. @ .98"

Edge acrylic failure at thickness transition

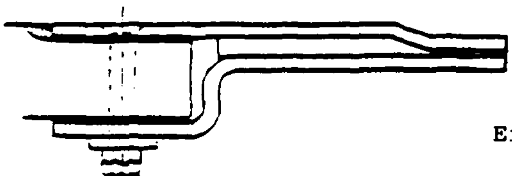
Configuration #5, Drawing 79202 - Baseline (.23 Acrylic)

P_{ULT} = 1625" @ δ = 1.08"

P_{YLD} = 712" @ δ = 0.28"

Edge failure in thickness transition

Configuration #6, Drawing 79204 - 400 Knot (.68 Acrylic Bonded)

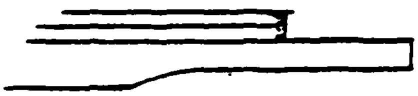


P_{ULT} = 2662 lbs. @ δ = 1.52"

P_{YLD} = 2212 lbs. @ δ = 0.82"

Either edge or acrylic failure at same load.

Configuration #7, Drawing 79209 - 400 Knot (.68 Acrylic Bolted)



P_{ULT} = 932 lbs. @ δ = 2.15"

No failure

Configuration #8, Drawing 79211 (Polycarbonate)

Figure 13. Summary of T-38 Laboratory Screening Tests (concluded).

tests were conducted for selected four-point flexure beams (4.50 inch 1/3 span) (2000 inches per minute) as follows:

Beam Configuration	Ultimate Load, Pounds
#1, 0.60 acrylic baseline	1000
#2, 0.90 acrylic 400 knot	1750
#4, polycarbonate 400 knot	1950 (no failure)

Since excessive deflection again resulted in edge pullout of the polycarbonate beam without failure, one additional test was conducted for the #4 beam configuration with impact at the 1/4 span points (3.375 inches from each end), resulting in an ultimate load at pullout of 2400 pounds, again without failure.

For all tests, load versus displacement data was stored in the digital memory of a transient recorder and played back at reduced speed on an X-Y recorder; high speed motion picture coverage was provided by WPAFB personnel. Information on edge response, fracture, and energy absorption provided by these laboratory screening tests has defined design deficiencies and allowed comparison of the relative merits of candidate design.

SECTION 6
FINITE ELEMENT STUDIES

The University of Dayton is conducting finite element studies in support of the T-38 birdstrike resistant transparency design efforts. The role of finite element analysis in the transparency design process is discussed in Reference 9.

Specifically, the studies are being conducted in two phases: (1) a number of parametric studies are being performed to generate design information, and (2) analysis of the final candidate design configuration is being performed.

The purpose of the parametric studies is to provide design information for the bird resistant crew enclosure designs. These parametric studies are being conducted using a representative monolithic transparency cross-section to achieve more economical run times. The effect of impacting energy levels (bird size and velocity), birdstrike location, transparency stiffness, and support structure stiffness on panel response, load path, and peak edge member inplane loads, shears, and bending moments is being studied. These studies are presently 90 percent complete for the forward windshield. The forward canopy analysis was not carried out because of the Air Force requirement to maintain through-the-canopy ejection capability.

It was originally planned that these studies would provide important input information into the initial design selection process. However, in order to meet the program schedule it was necessary to proceed without this information. Thus, the information will be available for evaluating performance and for the design iteration (if one is required).

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[9]B. S. West, The Role of Finite Element Analysis in the Design of Birdstrike Resistant Transparencies. (Paper presented at the Conference on Aerospace Transparencies, London England, September 8, 9, 10, 1980.)

Detailed analysis of the recommended forward windshield design configuration (AFWAL/FIEA Drawing No. 19260107-1) and the 0.90 inch stretched acrylic design is presently being accomplished. These analyses are being conducted to simulate the materially and geometrically nonlinear dynamic response.

All finite element studies are being conducted using MAGNA[10]. This code was developed by UDRI personnel and is especially suited for solving Materially And Geometrically Nonlinear dynamic Analysis (MAGNA) problems. The results of these studies will be reported in separate documentation.

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[10]R. A. Brockman, MAGNA Computer Program User's Manual. UDR-TR-80-107, November 1980.

SECTION 7
DETAIL DESIGN

Output from the forward (student) windshield development effort consists of the detail design of a developmental T-38 student windshield panel, AFWAL/FIEA Drawing No. 19260107-1. The drawing is in sufficient detail to support fabrication of full-scale transparencies. The minimum weight cross-sectional configuration selected to satisfy the four pound-400 knot bird-strike requirement basically consists of an 0.450 inch thick polycarbonate structural ply having an abrasion-resistant protective coating applied to the inner surface, and an 0.125 inch thick acrylic outer face ply coupled with an 0.050 inch thick interlayer. The polycarbonate member is integrated with the edge attachments; undercutting of the polycarbonate ply in edge areas being made in conjunction with a generous runout radius. All exposed laminate edges are sealed. Interchangeability with production transparencies has been maintained.

Design details are compatible with tooling considerations for producing parts on a mold, in addition to being free blown, in case tighter tolerances on curvature indicate potential for improved and/or more consistent optics performance. Material callouts have been made by utilization of appropriate controlling material properties rather than by specific designations.

SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

- Low level training missions and/or operating time at speeds above the existing T-38 crew enclosure damage threshold will result in flight safety risk to aircraft and crew. A demonstrated need exists for improved birdstrike protection.

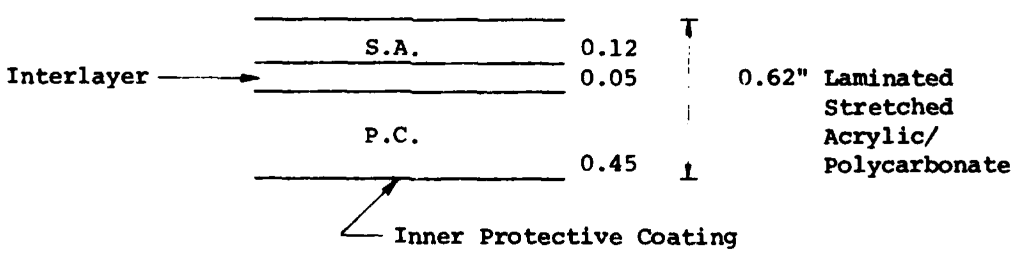
- Increased capability to defeat a four-pound bird impact at 400 knots is within the state of the art.

- Implementation can be by retrofit or attrition.

- The T-38 aircraft effectiveness/survivability will be enhanced by alternate T-38 transparencies.

Recommendations:

- For the forward (student) windshield, all the supporting parameters were carefully weighed and melded into a recommendation of the following windshield cross-section for full-scale hardware fabrication, testing, and evaluation.



Reference AFWAL/FIEA Drawing No. 19260107-01

- For the forward (student) canopy, incorporate a pyrotechnic fragmentation or comparable system into a birdstrike resistant transparency configuration such as those shown in Figure 9 to provide through-the-canopy ejection capability.

- For the aft (instructor) windshield, substitution of 0.460 thick coated polycarbonate for the existing stretched

acrylic panel should be considered in combination with the improved forward windshield until development of an improved alternate forward canopy is successfully completed. It is noted that the existing instructor windshield panel support structure is not capable of developing the required impact resistance provided for by a polycarbonate transparency.

SECTION 9

REFERENCES

1. F. L. Pretzer, R. L. Peterson, and B. S. West, "Design for Bird Impact: A Structural Systems Problem," paper presented at the Conference on Aerospace Transparent Materials and Enclosures, Long Beach, California, 24-28 April 1978; published as AFFDL-TR-78-168, December 1978.

2. B. S. West, and P. E. Johnson, "Laboratory Screening Tests: A Cost Effective Approach to Aircraft Transparency Design," paper presented at the Conference on Aerospace Transparent Materials and Enclosures, Long Beach, California, 24-28 April 1978; published as AFFDL-TR-78-168, December 1978.

3. B. S. West, "Design and Testing of F-111 Bird Resistant Windshield/Support Structure, Volume I - Design and Verification Testing," AFFDL-TR-76-101, Volume I, December 1976.

4. P. E. Johnson, "Design and Testing of F-111 Bird Resistant Windshield/Support Structure, Volume II - Mechanical Properties Evaluation," AFFDL-TR-76-101, Volume II, December 1976.

5. "Analysis of Shock-Absorbing Concepts for Bird-Proof Windshields of Advanced Air Force Vehicles, AFFDL-TR-74-155, February 1976.

6. "Bird Strike Capabilities of Transparent Aircraft Windshield Materials," AFML-TR-74-234, December 1974.

7. A. P. Berens, "Evaluation of the Birdstrike Threat to T-38 Transparencies," UDR-TM-79-12, University of Dayton Research Institute, Dayton, Ohio, July 1979.

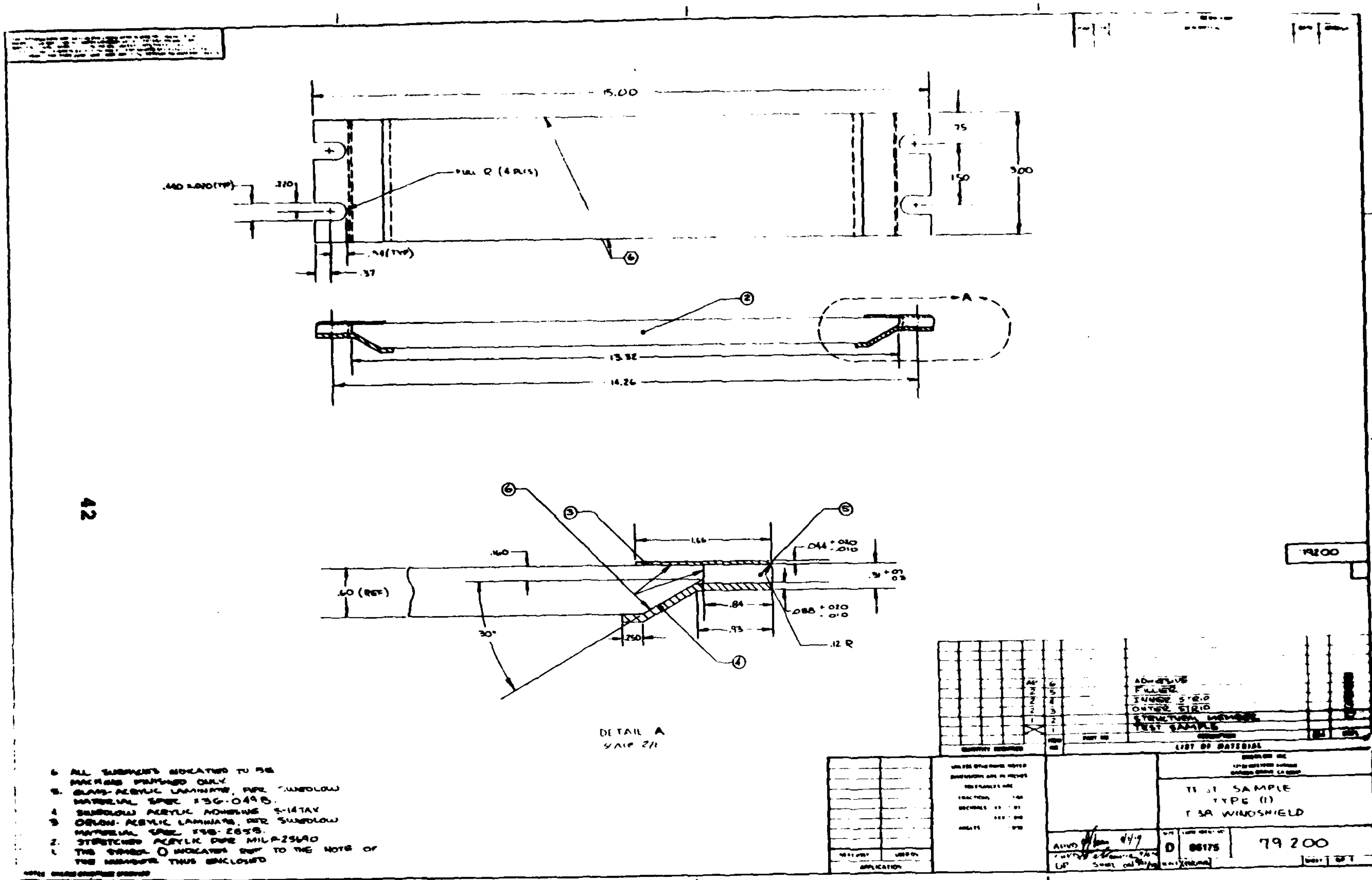
8. B. S. West, "Alternative T-38 Transparencies, Baseline Birdstrike Testing," AFWAL-TR-80-3132, Part II, November 1980.

9. B. S. West, "The Role of Finite Element Analysis in the Design of Birdstrike Resistant Transparencies," paper presented at the Conference on Aerospace Transparencies, London, England, September 8, 9, 10, 1980.

10. R. A. Brockman, "MAGNA Computer Program User's Manual," UDR-TR-80-107, November 1980.

APPENDIX

EDGE MEMBER BEAM TEST SPECIMEN DESIGN DRAWINGS



15.00
.75
1.50
3.00
.440 ±.020(TYP)
.220
FULL R (4 PLCS)
.56(TYP)
.37
13.32
14.26
A
DETAIL A
SCALE 2/1
1.66
.044 +.020 -.010
.160
.60 (REF)
.84
.93
.088 +.020 -.010
.12 R
.250
30°
ADHESIVE
FILLER
INNER STRIP
OUTER STRIP
STRUCTURAL MEMBER
TEST SAMPLE
LIST OF MATERIAL
TEST SAMPLE
TYPE (I)
T-38 WINDSHIELD
D
79200
6 ALL SURFACES INDICATED TO BE MACHINE FINISHED ONLY.
5 GLASS-ACRYLIC LAMINATE, PER SWEDLOW MATERIAL SPEC F56-0498.
4 SWEDLOW ACRYLIC ADHESIVE S-1474X
3 ORLON-ACRYLIC LAMINATE, PER SWEDLOW MATERIAL SPEC F56-2858.
2. STRETCHED ACRYLIC PER MIL-P-25690
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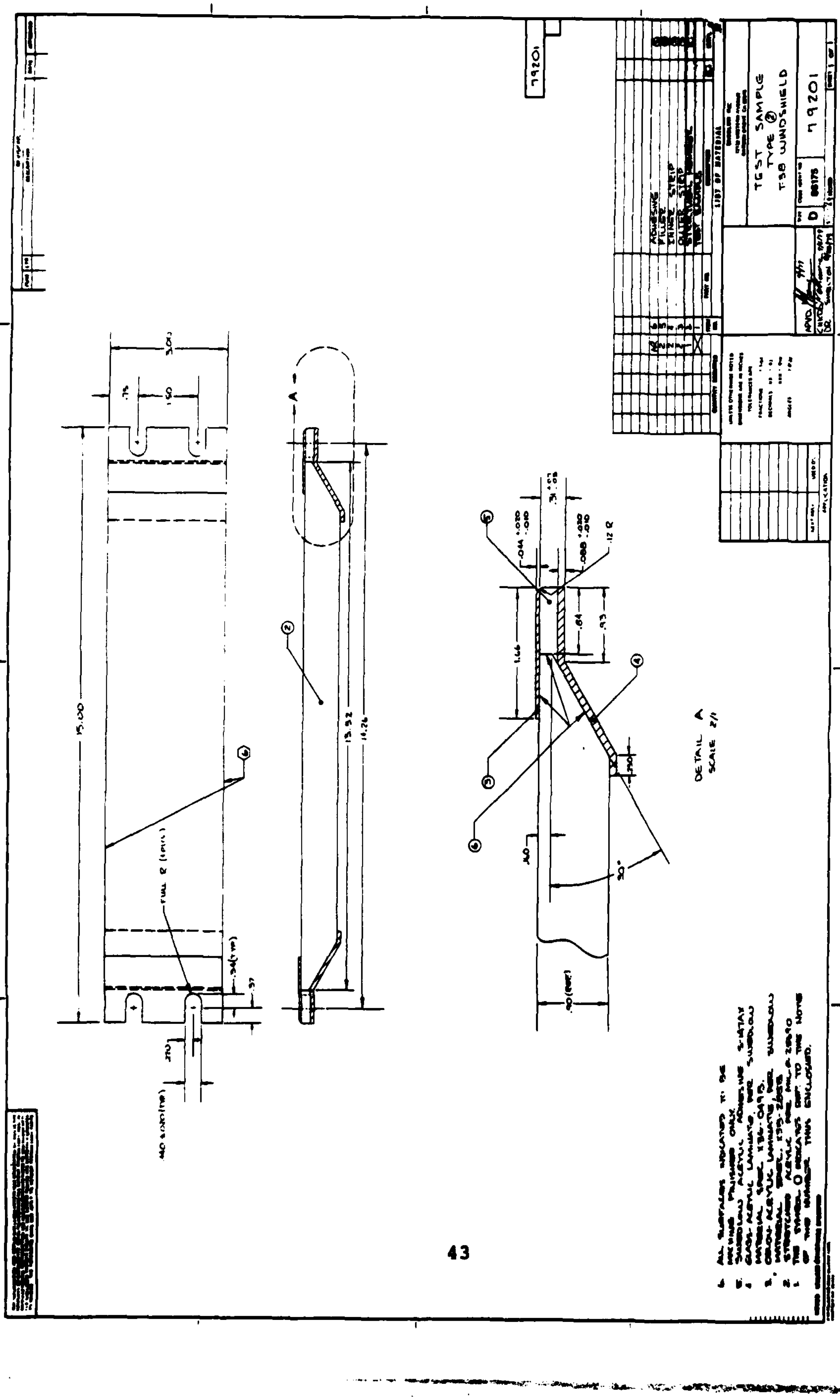
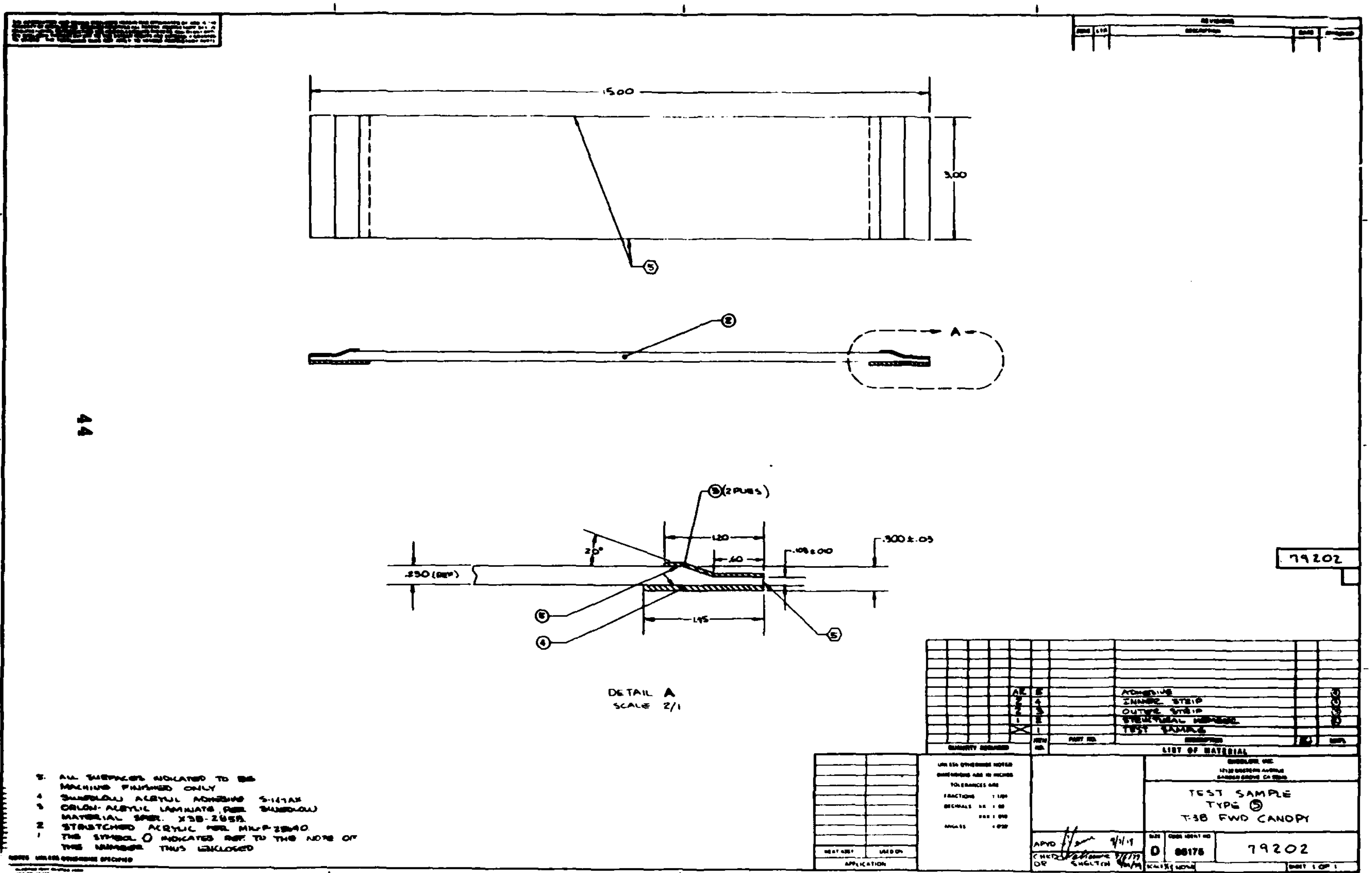
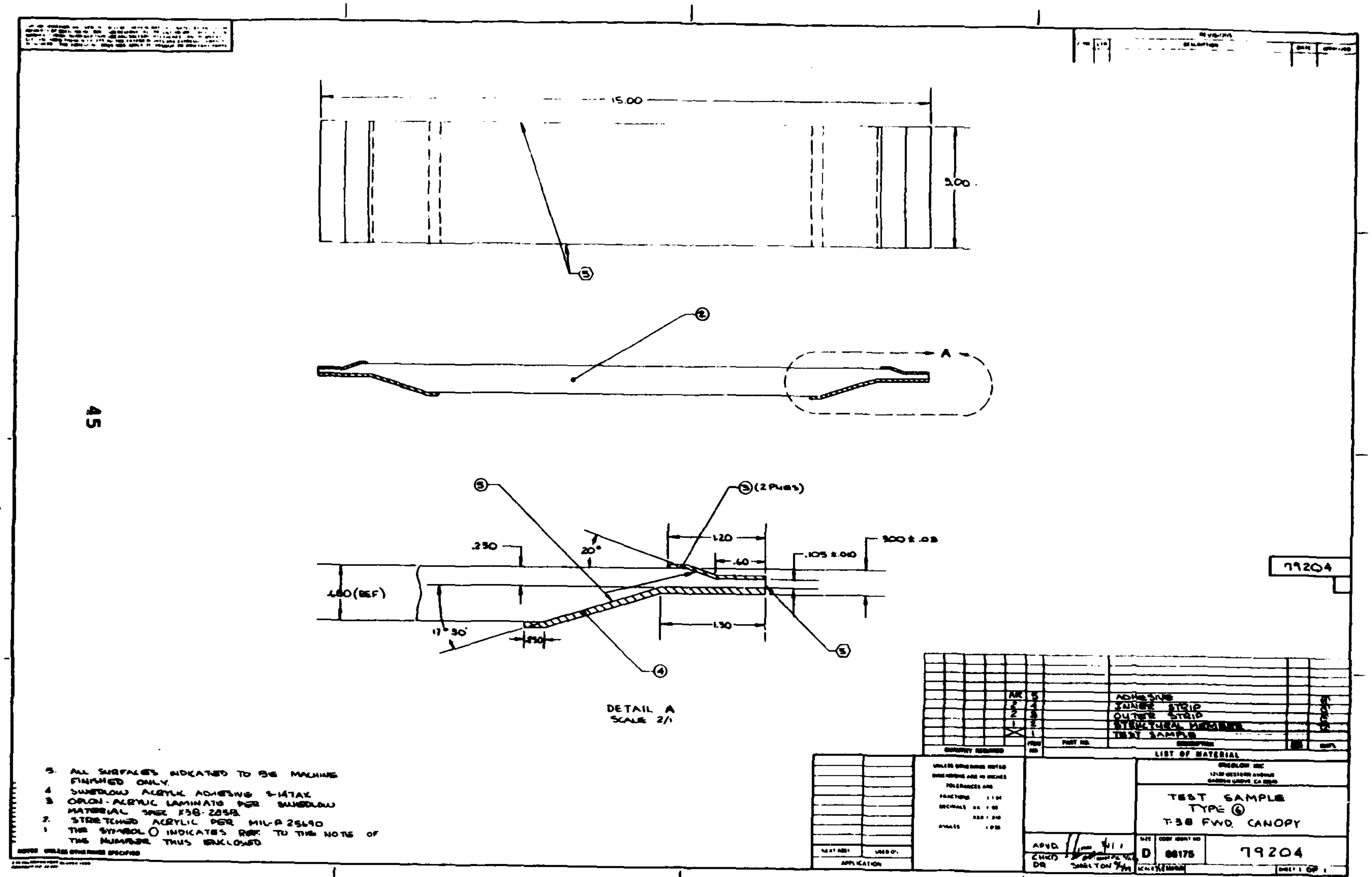
NOTES UNLESS OTHERWISE SPECIFIED



TEST SAMPLE
TYPE 2
T38 WINDSHIELD
79201
LIST OF MATERIAL
DETAIL A
SCALE 2/1



15.00
3.00
A
.300 ± .05
.105 ± .010
1.20
.60
20°
.250 (REF)
1.45
(2 PLIES)
DETAIL A
SCALE 2/1
5. ALL SURFACES INDICATED TO BE MACHINE FINISHED ONLY
4 SWEDLOW ACRYLIC ADHESIVE S-141AX
3 ORLON-ACRYLIC LAMINATE PER SWEDLOW MATERIAL SPEC. X38-285A
2 STRETCHED ACRYLIC PER MIL-P-25690
1 THE SYMBOL ○ INDICATES REF. TO THE NOTE OF THE NUMBER THUS ENCLOSED
NOTES UNLESS OTHERWISE SPECIFIED
ADHESIVE
INNER STRIP
OUTER STRIP
STRUCTURAL MEMBER
TEST SAMPLE
LIST OF MATERIAL
TEST SAMPLE
TYPE 5
T-38 FWD CANOPY
D
86175
79202
APVD
CHKD
DR
SHELTON
SHEET 1 OF 1
79202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3.00
A
DETAIL A
SCALE 2/1
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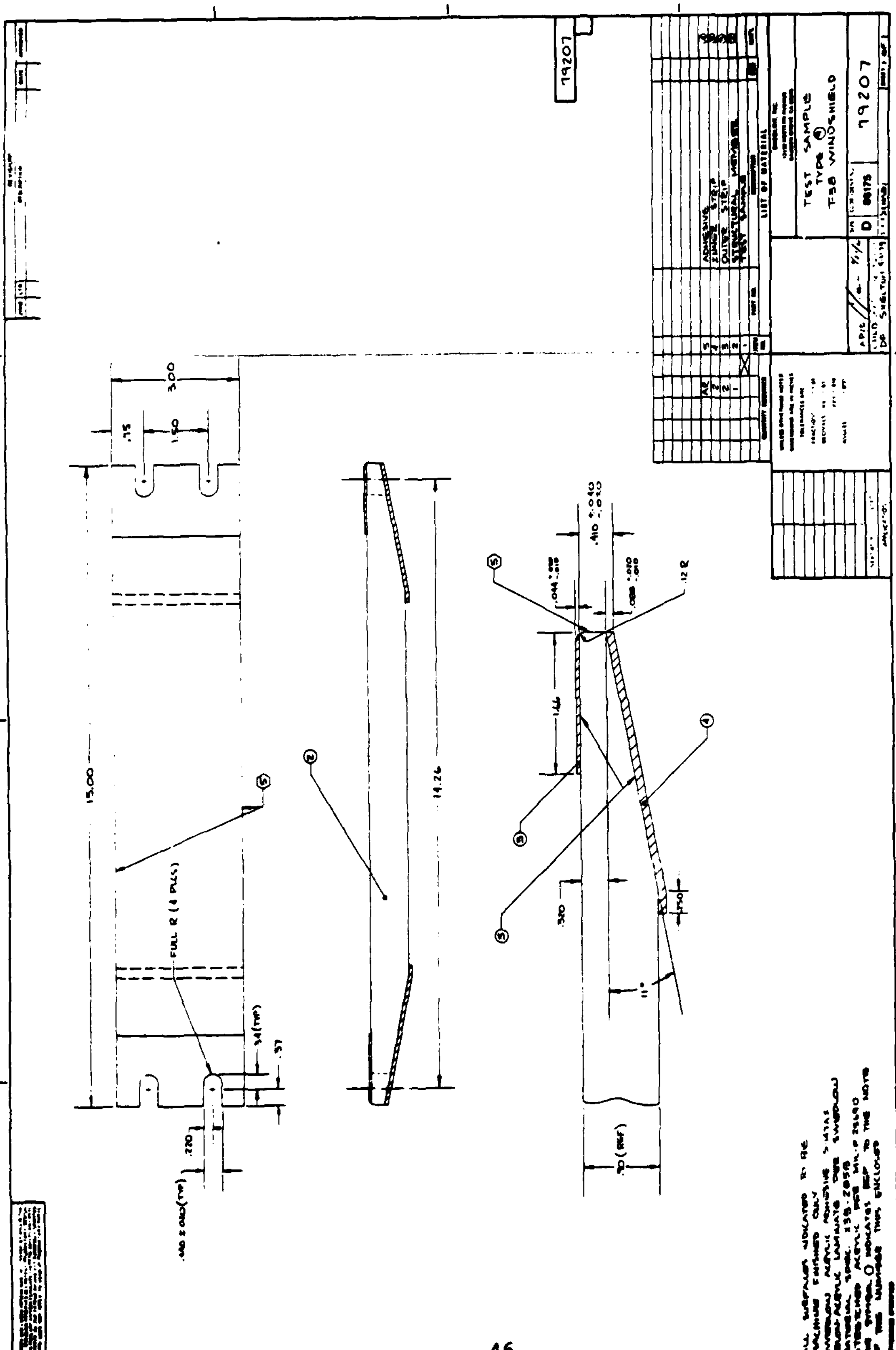
20°
1.20
.60
.105 ±.010
.300 ±.03
.480 (REF)
17° 30'
.250
1.30
(2 PLIES)
ADHESIVE
INNER STRIP
OUTER STRIP
STRUCTURAL MEMBER
TEST SAMPLE
LIST OF MATERIAL
TEST SAMPLE
TYPE 6
T-38 FWD. CANOPY
D
08175
79204
79204
5. ALL SURFACES INDICATED TO BE MACHINE FINISHED ONLY.
4 SWEDLOW ACRYLIC ADHESIVE S-147AX
3 ORLON-ACRYLIC LAMINATE PER SWEDLOW MATERIAL SPEC X38-285B
2. STRETCHED ACRYLIC PER MIL-P-25690
1 THE SYMBOL ○ INDICATES REF. TO THE NOTE OF THE NUMBER THUS ENCLOSED
NOTES UNLESS OTHERWISE SPECIFIED



79207
TEST SAMPLE
T-38 WINDSHIELD
LIST OF MATERIAL
ADHESIVE
OUTER STRIP
STRUCTURAL MEMBER
TEST SAMPLE
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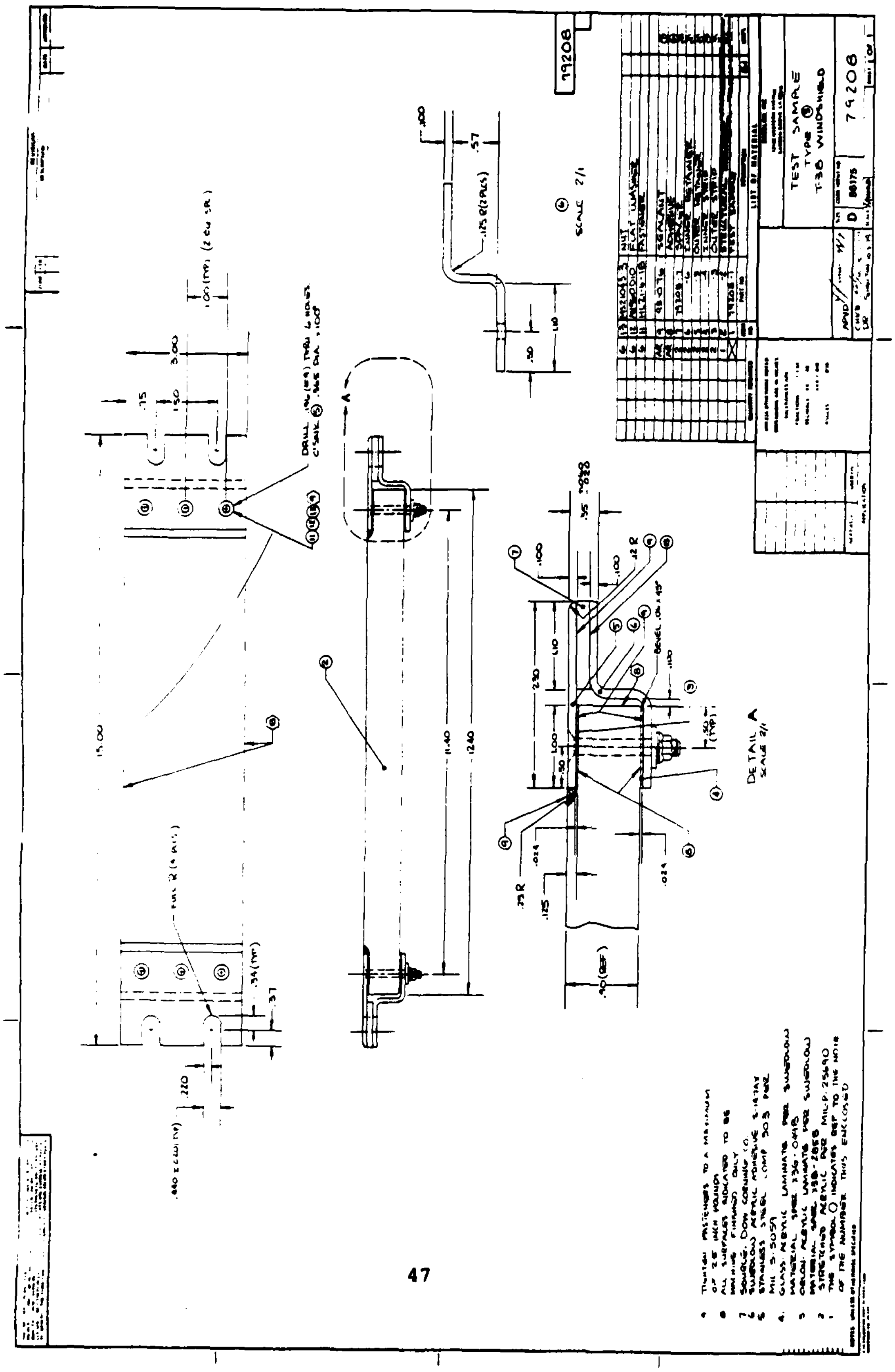
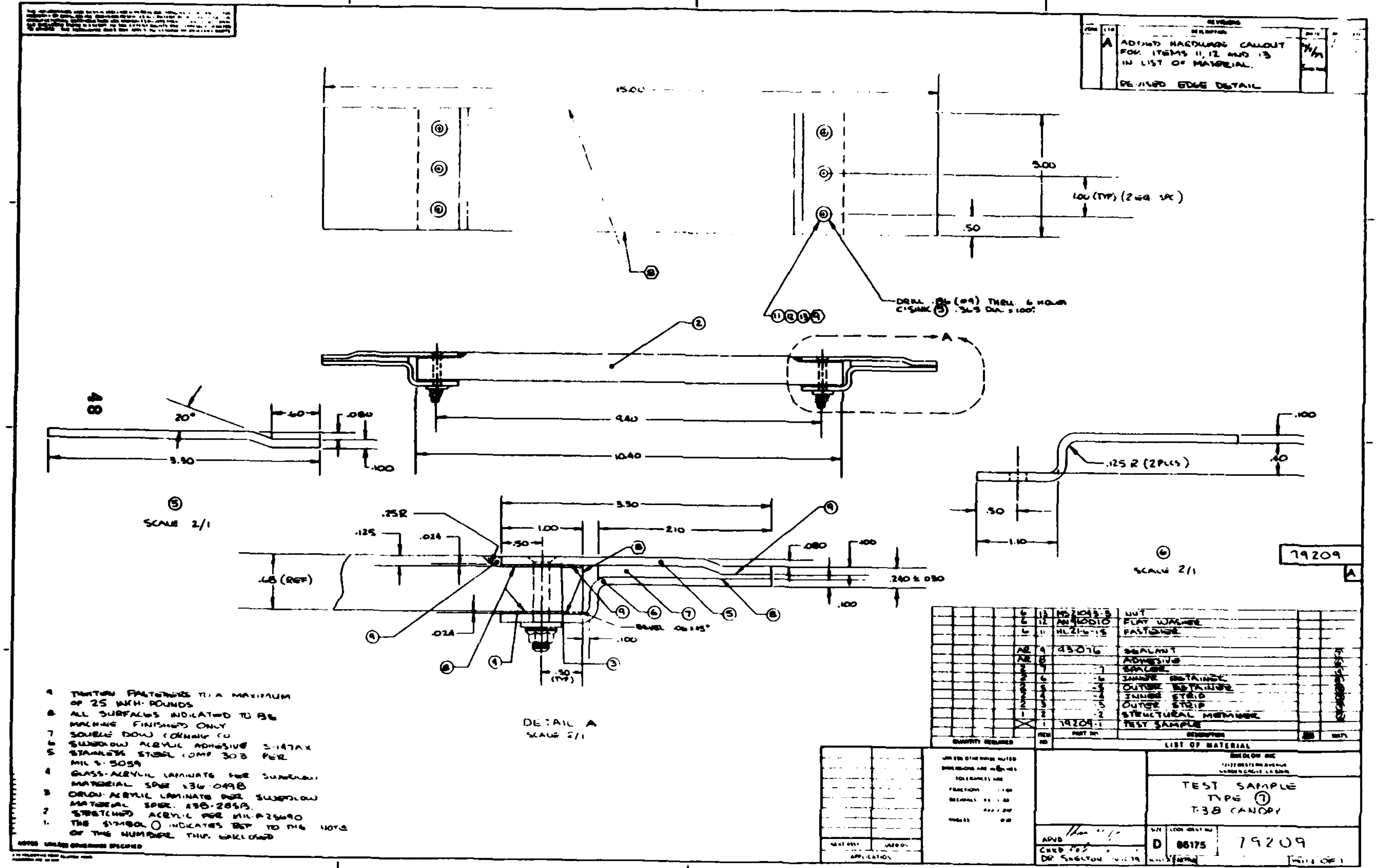
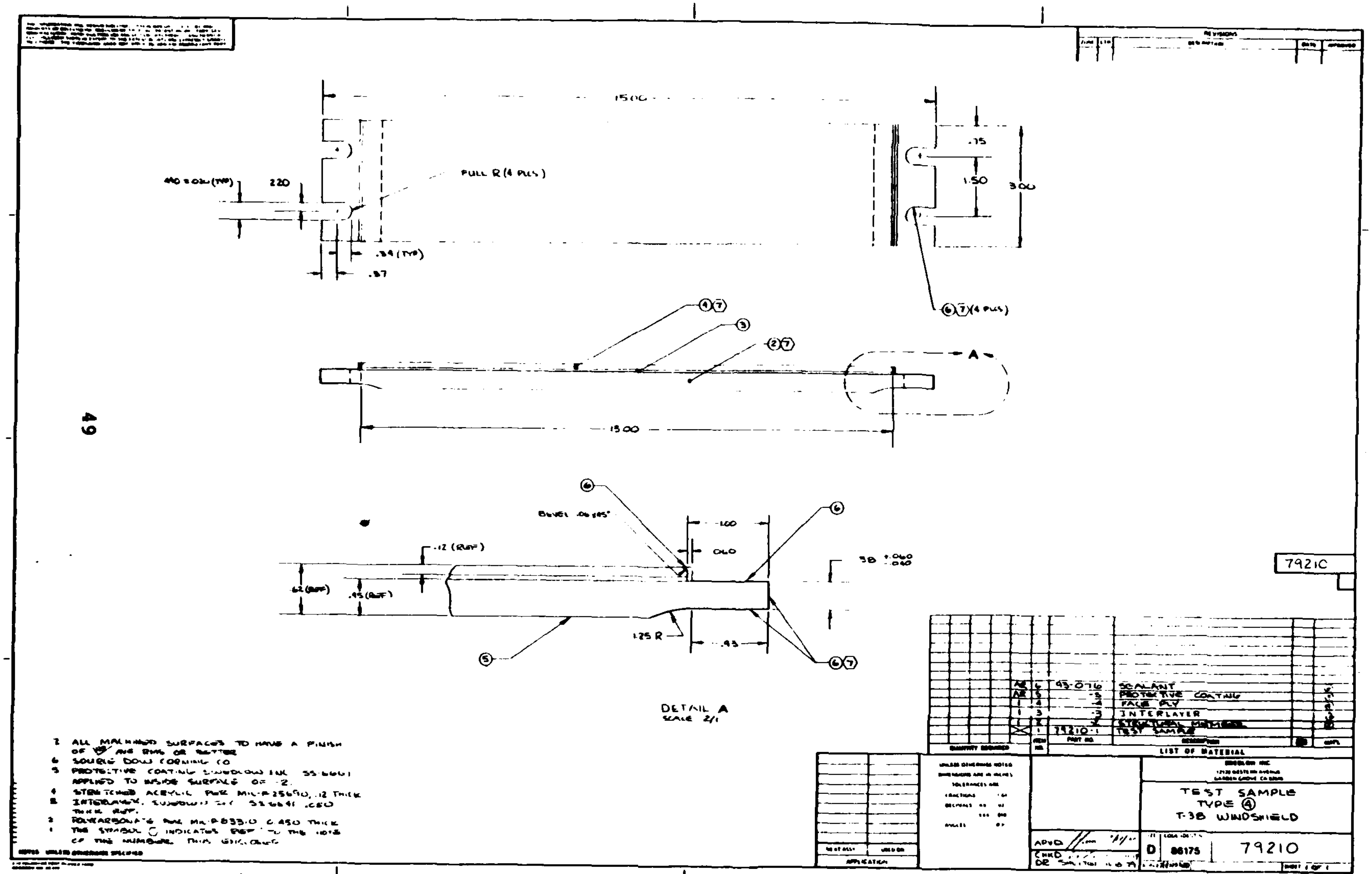
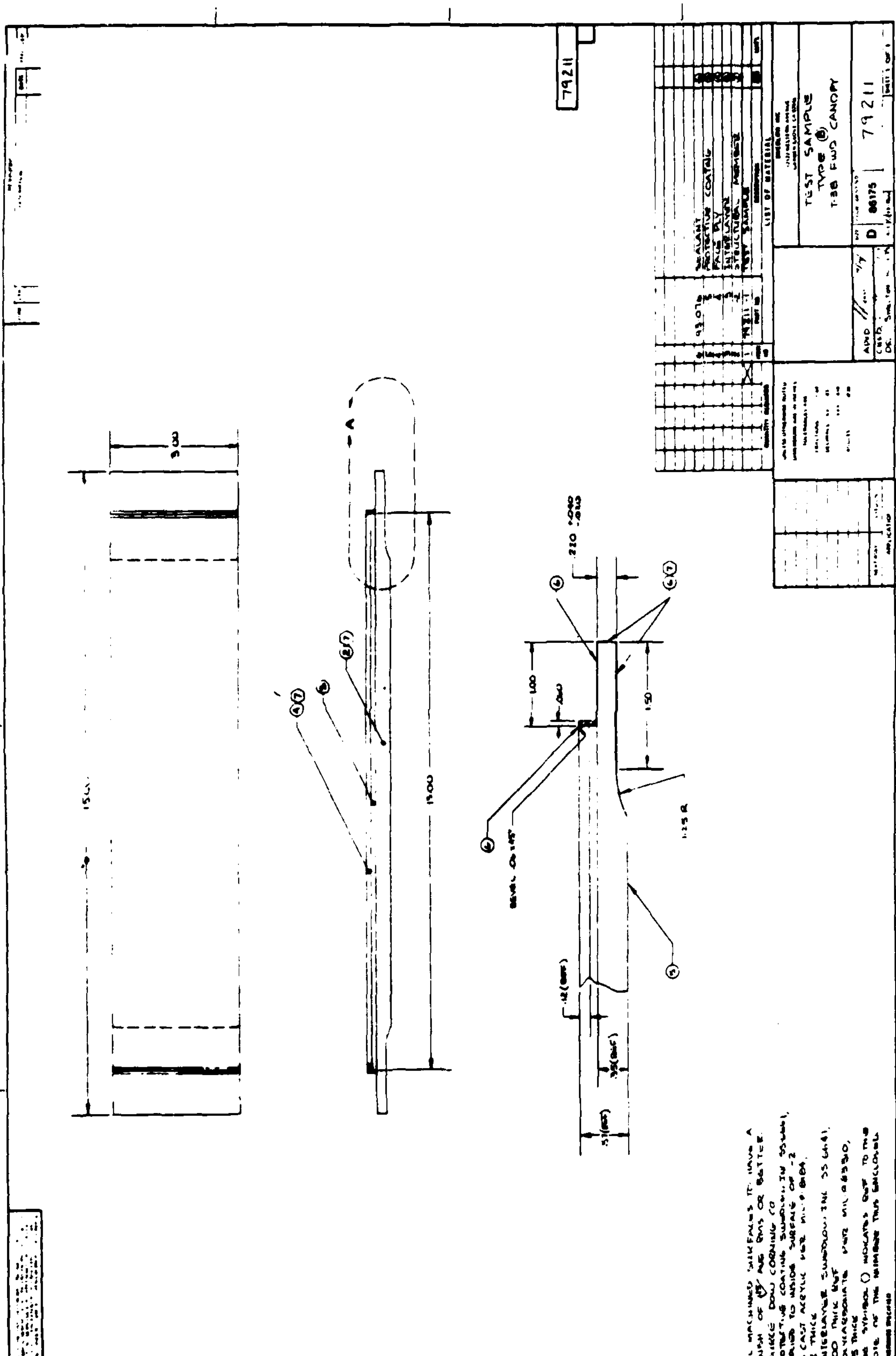
3.00
1.50
.75
FULL R (4 PLCS)
1.66
.410
11°


TEST SAMPLE
TYPE 8
T-38 WINDSHIELD
79208
DETAIL A
SCALE 2/1
SCALE 2/1
LIST OF MATERIAL



ADDED HARDWARE CALLOUT FOR ITEMS 11, 12 AND 13 IN LIST OF MATERIAL.
REVISED EDGE DETAIL
15.00
3.00
1.00 (TYP) (2 EQ SPC)
.50
DRILL .196 (#9) THRU 6 HOLES
C'SINK .365 DIA x 100°
9.40
10.40
20°
.60
.080
.100
3.30
SCALE 2/1
.125 R (2 PLCS)
.40
.50
1.10
SCALE 2/1
.25R
.125
.024
.50
1.00
3.30
2.10
.48 (REF)
.240 ± .030
BEVEL .06 x 45°
DETAIL A
SCALE 2/1
9 TIGHTEN FASTENERS TO A MAXIMUM OF 25 INCH-POUNDS
8 ALL SURFACES INDICATED TO BE MACHINE FINISHED ONLY
7 SOURCE DOW CORNING CO
6 SWEDLOW ACRYLIC ADHESIVE S-147AX
5 STAINLESS STEEL COMP 303 PER MIL-S-5059
4 GLASS-ACRYLIC LAMINATE PER SWEDLOW MATERIAL SPEC 136-049B
3 ORLON-ACRYLIC LAMINATE PER SWEDLOW MATERIAL SPEC 138-265B
2 STRETCHED ACRYLIC PER MIL-P-25690
1. THE SYMBOL ○ INDICATES REF TO THE NOTE OF THE NUMBER THUS ENCLOSED
NOTES UNLESS OTHERWISE SPECIFIED
6 13 MS21043-3 NUT
6 12 AN960C10 FLAT WASHER
6 11 HL21-6-15 FASTENER
AR 9 93-076 SEALANT
AR 8 ADHESIVE
2 7 -7 SPACER
2 6 -6 INNER RETAINER
2 5 -5 OUTER RETAINER
2 4 -4 INNER STRIP
2 3 -3 OUTER STRIP
1 2 -2 STRUCTURAL MEMBER
1 19209-1 TEST SAMPLE
QUANTITY REQUIRED
ITEM NO
PART NO
DESCRIPTION
LIST OF MATERIAL
TEST SAMPLE
TYPE 7
T-38 CANOPY
APVD
CHKD
DR SHELTON
D
86175
79209
A


15.00
PULL R (4 PLCS)
.220
.34 (TYP)
.87
.15
1.50
3.00
⑥⑦(4 PLCS)
④⑦
③
②⑦
A
Bevel .06 x 45°
.100
.060
.38 ±.060
.12 (REF)
.62 (REF)
.45 (REF)
1.25 R
.93
DETAIL A
SCALE 2/1
7 ALL MACHINED SURFACES TO HAVE A FINISH OF 125 RMS OR BETTER
6 SOURCE DOW CORNING CO
5 PROTECTIVE COATING SWEDLOW INC. SS-6601 APPLIED TO INSIDE SURFACE OF -2.
4 STRETCHED ACRYLIC PER MIL-P-25690, .12 THICK
3 INTERLAYER, SWEDLOW INC. SS-6641 .060 THICK REF.
2 POLYCARBONATE PER MIL-P-83310 .0.450 THICK
1 THE SYMBOL ◯ INDICATES REF. TO THE NOTE OF THE NUMBER THUS ENCLOSED
NOTES UNLESS OTHERWISE SPECIFIED
SCALANT
PROTECTIVE COATING
FACE PLY
INTERLAYER
STRUCTURAL MEMBER
TEST SAMPLE
LIST OF MATERIAL
79210-1
TEST SAMPLE
TYPE ④
T-38 WINDSHIELD
D 86175 79210
7921C



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